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Granular Activated Carbon Usage
Montipora digitata Husbandry
Tridacna Clam Coloration
Angelfish in the Home Aquarium



photographs by Teresa Zuberbühler

CHIEF EDITOR

Terry Siegel
(terry@advancedaquarist.com)

**WEBSITE AND PRINT
DESIGNERS**

Shane Graber (liquid@reefs.org)
Leonard Ho (len@reefs.org)

FEATURED AQUARIUMS

D. Wade Lehmann (wade@reefs.org)

ADVERTISING

Leonard Ho
(advertising@advancedaquarist.com)

COVER PHOTO

Emperor Angelfish, *Pomacanthus imperator*, adult (large photo) and juvenile (small photo). Photos by Teresa Zuberbuhler

WEBSITE & FEEDBACK

Advanced Aquarist:
<http://www.advancedaquarist.com/>

Feedback:
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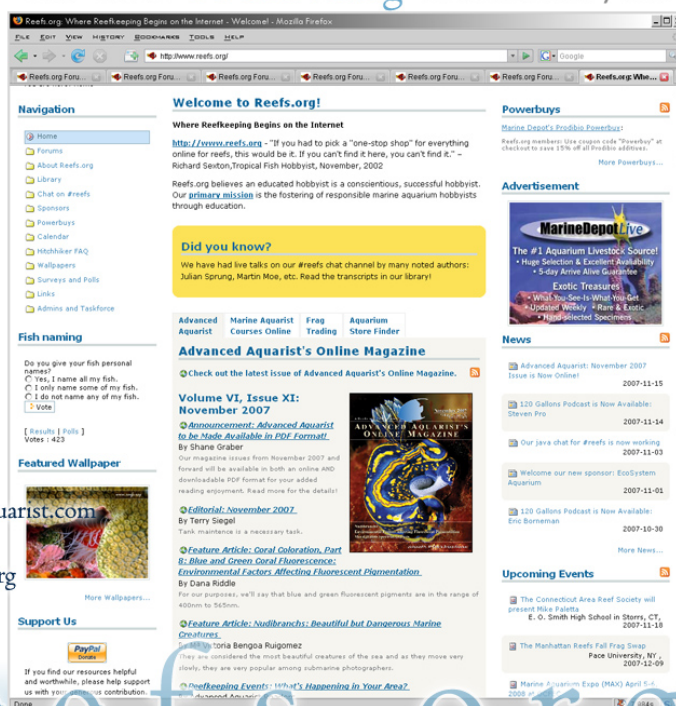


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EDITORIAL

JANUARY 2008

By Terry Siegel

To our readers from all over planet Earth, Happy New Year.

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In our first issue for the new year we present part 1 of a paper entitled, **Granular Activated Carbon: Modeling of Operational Parameters for Dissolved Organic Carbon Removal from Marine Aquaria**, by Ken S. Feldman, Lauren F. Vernese, Karl T. Mueller, and Kelly Maers, from the Chemistry Department, The Pennsylvania State University. I'm particularly excited about this study because it applies hard science to a subject that has had enumerable anecdotal observations about why, how, how much, and how often to use activated carbon in marine aquaria. Because the observations were anecdotal they were contradictory, if not simply filled with misinformation. With this study we now have some quantifiable data. For lay people the paper in its entirety may be a little tough reading, but with some mental sweat the reader will find some very valuable information about the use of activated carbon.

SCRATCHES AND ACRYLIC AQUARIA

Keeping a large reef tank that is made of acrylic is far more difficult than I had imagined. I was warned by some of my reef keeping friends that keeping coralline algae off of the front pane would be a burden – I must admit that they were right. Essentially, I had little choice: I couldn't find anyone that would build a glass reef tank on location, and the configuration of my house made it impossible to bring a glass reef tank of the size I wanted into the only location available to me. As far as the animals are concerned a glass or acrylic cage is irrelevant, but to me keeping the coralline off of the front pane is extremely difficult. And, as

some of you know I have experimented with plastic blades and a variety of tools, which to some degree work, but nonetheless, I frequently scratch the acrylic front pane both inside and out. To exacerbate the problem coralline algae apparently loves to attach to plastic, and especially to scratches in the plastic. What to do about this, is the question. One answer follows. A company called Everclear Transparency Refurbishing, Inc. seems to have the best solution I've seen so far. The following exchange took place with me and them very recently:

From: Scott Berentsen [mailto:scott@etr-inc.com]

Good to hear it works well on the outside. As for the inside, I originally sent you a **Magnet Kit** that works with any Magnavore magnet. This is a very popular kit because it allows you to remove the inside scratches while keeping the reef intact. We have developed the same kit to work with Algae Free magnets as well.

Tips, first try and remove the deepest scratches, either by hand or using the magnet. If there are a lot of scratches throughout, you may just want to refurbish the entire panel. Take a look at the magnet kit instructions and let me know if you have any questions.

By the way, we use the magnet scratch removal system in our commercial services and it works well. As with any scratch removal, it does require quite a bit of time and energy.

For the future, we are working on some innovative solutions. First, for the outside, we are now offering a **protective film** that serves as a sacrificial, replaceable layer. Eventually we'll be offering it for the inside as well. We are also doing R&D on some tools that will make scratch removal more automated.

Regards, Scott
 Everclear Transparency Refurbishing Inc. www.etr-inc.com

Hi Scott,

Yesterday I finally got around to using your underwater kit, and much to my amazement it worked quite well. Hair line scratches, which represent the vast majority, which resulted from coralline algae removal, were relatively easily removed using the **Magnet Kit**. A few deeper scratches required a lot of elbow grease, with the result that I'm looking forward to your R&D results.

Terry Siegel, Editor



FEATURE ARTICLE

GRANULAR ACTIVATED CARBON, PART 1: MODELING OF OPERATIONAL PARAMETERS FOR DISSOLVED ORGANIC CARBON REMOVAL FROM MARINE AQUARIA

By Ken S. Feldman, Lauren F. Vernese, Karl T. Mueller, Kelly Maers

Chemistry Department, The Pennsylvania State University. In this first part of a two part series, the authors will introduce granular activated carbon and explain the experimental goals and mathematical models used in their research.

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INTRODUCTION

GAC AND THE AQUARIUM

The use of granular activated carbon (GAC) for decolorizing marine aquarium water has had a long and successful history. In fact, prior to the introduction of this filtering agent into the salt-water aquarium hobby, the central role of this technology in water remediation efforts ensured that a large body of data existed which spoke to the basics of contaminant removal from drinking water and wastewater by carbon-based media (Bansal, 2005; Cheremisinoff, 1993; Kvech, 1997). Through extensive experimental and theoretical (i.e., model building) studies, many of the parameters that define success have been identified. Optimization of GAC source, water flow rate through fixed-bed reactors, media presentation, and time-in-use, among other features, has led to successful protocols for the removal of many small-molecule organic contaminants, such as benzene, phenol, chlorinated hydrocarbons, pesticides, etc. from potable water sources (Bansal, 2005; Khan, 1997; Singh, 2006). It is not surprising that many of the lessons learned from these studies accompanied the technology as it was adapted to marine aquarium use. Some empirical and largely divergent "rules for use", which have emerged from these initial inputs combined with the numerous observations of aquarists, have been proposed by many authors (<http://www.carbochem.com/activatedcarbon101.html>; <http://www.articlefishtalk.com/Article/Activated-Carbon-in-the-Aquarium/78>; Hovanec, 1993; Harker, 1998; Schiemer, 1997). Although there is by no means a uniform consensus, recommendations 1 and 2 below seem to have stood the test of time. On the other hand, opinions conflict on the questions of how much (#3), how fast (#4), and how often (#5).

1. Use GAC formulated from either bituminous coal (Hovanec, 1993) or lignite coal (Harker, 1998), but not coconut shell.

2. Use active flow through the media and not passive diffusion (Hovanec, 1993; Harker, 1998).
3. Use about 0.3 gm of GAC per gallon of tank water ("3 table-spoons per 50 gallons") (Harker, 1998) to 19 gm/gal (Lliopoulos, 2002) (no consensus here).
4. Use water flow rates of about 4 gph (Harker, 1998) to several hundred gph [many canister filter manufacturers] (again, no consensus).
5. Replace with new GAC every week (Harker, 1998) to once every 4-6 weeks (Schiemer, 1997) (once again, no consensus).
6. Run continuously (Schiemer, 1997) or sporadically (Harker, 1998) (no consensus!).

DISSOLVED ORGANIC CARBON

The precise chemical species that GAC removes have not been determined. Rather, the catchall phrases "DOC" (dissolved organic carbon) and/or "marine humic/fulvic acids" are frequently employed to categorize the uncharacterizable (Holmes-Farley, 2004; Bingman, 1996; Rashid, 1985; Romankevich, 1984). In fact, both descriptors have little intrinsic meaning and give no insight into the actual chemicals involved. Romankevich has estimated that there is approximately 2×10^{12} tons of DOC in the world's oceans (for comparison, Romankevich reports that there are approximately 2.5×10^{12} tons of organic carbon in oil deposits in the world), and about 94% of that material is phytoplanktonic in origin (Romankevich, 1984). Most (all?) of these dissolved organic materials are subjected to both biological (bacterial) and non-biological degradative processes until eventually refractory (= inert) compounds, which survive exposure to the marine environment's inhabitants and conditions, result. Occasionally, marine scientists have attempted to provide some structural details for these substances on the basis of the spectroscopic

signatures of specific chemical functionalities observed. In particular, solid-state carbon nuclear magnetic resonance spectroscopy has provided an unrivaled window into this complex problem (Gillam, 1986; Sardessal, 1998). Representative polycyclic species derived from oxidation and then cyclization of unsaturated lipids have been proposed (Harvey, 1983), whereas other authors have suggested that some humic acid components originate from oligosaccharide-protein condensations to form polycyclic materials that have a high nitrogen content (Francois, 1990). The former process has a direct analogy to the curing of oil-based varnishes for wood treatment, whereas the latter process is related to the chemistry of food browning upon cooking, a sequence of transformations called the Maillard reaction. In both cases, colored, soluble material can be formed. Both of these chemical transformations require condensation of different chemical reaction partners that each exist in concentrations of approximately 1 ppm, and so any hypothesis for DOC formation that cites these reactions must address this low-concentration-of-reactants issue.

OUR EXPERIMENTAL GOALS

With this information as background, we set out to experimentally probe some of the unresolved issues surrounding the use of GAC in the marine aquarium:

1. How much GAC should be used to deplete the DOC by 90% (arbitrarily chosen) for a given water volume?
2. When should the GAC charge be changed?
3. Does GAC differentially remove different types of arguably reef-relevant organic molecules with different facility? That is, are all yellow, or more generally, colored, compounds removed with equal facility, and are there non-yellow-colored but possibly undesirable organic compounds that GAC removes as well?
4. How does the rate of impurity removal relate to water flow rate?
5. Do organics leach back out of GAC upon saturation?

Some tentative answers (not THE answers) to these questions are presented below.

Prior to framing these questions in experimentally addressable terms, some basics must be considered: For example, what experimental quantity should be measured - the amount of the impurity that a given amount of GAC removes, or the rate by which the GAC removes the impurity? Actually, both quantities will be required to address these questions. Historically, measurements of the ability of GAC to remove an impurity from water have looked at both issues.

Some background:

1. **Thermodynamics.** Thermodynamic measurements attempt to describe the quantity of impurity that can be removed by a given quantity of GAC (Suzuki, 2004; Walker, 2000). These types of measurements are run to "infinite" time; that is, the system (= GAC + impurity in water) is allowed to settle until the measured concentration of impurity in the water is constant; or, in chemical terms, the system has reached *equilibrium*. From these measurements of GAC's adsorbing capacity (different for each chemically unique impurity) and application of mathematical treatments relying on either the Freundlich or Langmuir isotherms [Potgieter, 1991], many useful system parameters can be calculated. This type of analysis provides data pertaining to which type of GAC can adsorb the most impurity-per unit-weight. Many authors have applied this technique in analyzing the use of GAC with marine aquaria, and some of their conclusions (cf. # 1 and # 5 in the Introductory section) have been presented. These data do not address how fast impurities are removed.
2. **Kinetics.** Kinetic measurements attempt to describe how fast GAC removes an impurity (Ganguly, 1996; Baup, 2000). These data do not reveal the ultimate adsorption capacity of the GAC. The kinetic approach to developing figures of merit for GAC has been explored by some aquarist authors (Cerreto, 2006; Walker, 1999; Harker, 1998), and conclusions about active vs. passive flow (# 2 above), preferred type of GAC precursor (#1 above), and amount of GAC to use (# 3 above) have been derived from these data.

It should be emphasized that the kinetic approach and the thermodynamic approach actually measure different things, and data garnered from these two different experimental protocols will not necessarily lead to the same conclusions about which is the "best" GAC, depending upon the criteria used to define "best". It is possible, for example, for a particular sample of GAC to remove an impurity very rapidly but actually have a rather low capacity. Conversely, another sample of GAC may exhibit the exact opposite behavior; there is no reason why the kinetics of impurity removal and the capacity of the GAC sample should correlate or even run in parallel.

These assertions can be better understood when viewing GAC on the molecular level. As many authors have detailed in earlier accounts (Hovanec, 1993; Kvech, 1997), GAC is essentially a refractory solid honeycombed with passages and chambers that are chemically active enough to bind some types of organic molecules. The sizes of the interior spaces are exceedingly heterogeneously distributed, and vary as per the technique(s) used to activate the carbon. Likewise, the chemical nature of the active binding surfaces is heterogeneous and the details of the surface molecular constituents depend upon the activation procedure. This heterogeneity all works towards the good, as GAC in the aggregate then offers many differently sized and functionally distinct binding sites to act as complementary partners for the myriad of structurally different organic impurities that might be found in a marine aquarium, lumped under the aegis of DOC. The thermodynamics (= capacity at equilibrium) of impurity removal typically scales with the number, or amount, of available binding sites for impurities. If a GAC sample has a greater porosity due to

its activation procedure, it will have the capacity to trap and hold more impurity. The kinetics (= rate of impurity capture) of DOC removal is dependent on several factors: (a) the rate of diffusion of the impurity to the surface of the GAC particle, (b) the rate of diffusion of the impurity inside the potentially restricting space of the pores, (c) the rate of surface diffusion once the impurity is bound, and (d) the strength of the specific molecular-level interactions between the GAC surface and the impurity in question. All of these rate components are sensitive to the specific shape, charge, size and chemical functionality of the impurity. Therefore, there is no real correlation, or expectation of a correlation, between the amount of surface area for binding within the pores and channels in GAC (proportional to thermodynamic capacity) and the diffusion rates and surface chemistry within these pores and channels (influences the kinetic rate of removal).

Both kinetic and thermodynamic data are necessary for probing the central questions outlined above. Quantifying the rates of impurity removal (kinetics) as a function of different chemical impurity structures will allow question (3) to be tested, whereas the kinetic approach will directly address the questions posed in (1) and (4). Measurement of impurity leaching rates of impurity-saturated GAC (question (5)) will address concerns that used GAC itself might be a source of DOCs if not removed when saturated. Finally, the GAC's thermodynamic adsorption capacity should provide direction with question (2).

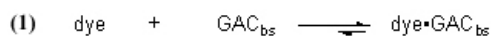
THE MATHEMATICAL MODELS

There are two distinct tank scenarios that require different mathematical models to obtain useful information.

1. There is a fixed amount of impurity (DOC), and no more is being added, at least at a rate competitive with the rate of impurity removal by the GAC. This case most likely might be encountered if GAC has not been used for a while, and so the DOC level has built up, or if the tank has been medicated, and it is important to remove excess medication quickly. The key question here is, "How much GAC should I use to remove this large amount of impurity?"
2. GAC is in continuous use, and the steady-state DOC level reflects the trade-off between the rate of DOC introduction by biological processes, and the rate of DOC removal by the GAC. This situation would pertain if GAC is used continuously. The key question here is, "When should I change my GAC?"

We will first examine scenario (1), and then use the results obtained to arrive at an approach to address scenario (2).

The fundamental Case 1 chemical equation that describes the removal of an organic dye molecule (as a model for DOC) from solution by GAC is



Note that this equation does not have any provision for adding dye to the water, and so it describes Case (1) and not Case (2). The symbol "GAC_{bs}" in this chemical equation is defined for our purposes as one binding site in the GAC matrix. In words, this equation indicates that one molecule of dye (or one mole, which

equals 6.02×10^{23} molecules - it is often convenient to discuss chemical process in terms of moles, or fractions of a mole - millimol, micromol, etc.) binds to one binding site in the GAC (or one mole of binding sites) and therefore is removed from solution. An assumption of this model is that the dye can leach from the GAC and reenter the solution, leading to a situation called "equilibrium binding". That is, the GAC will become saturated with dye at some point, and that saturation point is a complex function of how much dye is present, how much GAC is present, and the molecular-level affinity of the GAC for the dye. A test of this assumption will be described later in the article. This one-to-one interaction between the dye molecule and a GAC binding site (GAC_{bs}) lends itself to a mathematical analysis characterized by the relationship in Eq. (2). In words, this expressions indicates that the rate of removal of dye from solution (symbolized by the differential $-d[\text{dye}]/dt$, t = time in minutes) is proportional to the product of the concentration of dye (in moles per liter, often abbreviated as mol/L, or M, and indicated by the symbol $[\text{dye}]$), and the concentration of GAC binding sites available ($[\text{GAC}_{\text{bs}}]$, in moles per liter of total solution). Of course, the GAC binding sites are not spread throughout the whole solution, but rather they are confined to the GAC particles in a Phosban (or equivalent) reactor. However, the experimental design is such that this distinction is not significant. This proportionality expression can be converted to an equality by including a constant of proportionality denoted as k (Eq. (3)).

$$(2) \quad -\frac{d[\text{dye}]}{dt} \propto [\text{dye}][\text{GAC}_{\text{bs}}]$$

$$(3) \quad \frac{d[\text{dye}]}{dt} = -k[\text{dye}][\text{GAC}_{\text{bs}}]$$

Although it may seem that the introduction of this "fudge factor" k is somewhat arbitrary and perhaps not even germane to the problem, it turns out that it is possible to use this single figure-of-merit to describe the key rate characteristics of the system - k is often called a *rate constant*. The larger k is, the faster that the GAC removes the dye from solution. Note that k is independent of the amount of GAC used - in principle, the same k should be obtained for any amount of GAC from the same source. In practice, we shall see that the reality is somewhat different, perhaps reflecting the crudeness of some of the assumptions of our model, and the inconsistencies that attend any repetitive experimental measurement procedure. Whereas the rate constant k should be invariant with respect to GAC amount, the actual rate of dye removal ($d[\text{dye}]/dt$) is a function of the amount of GAC present, since the amount of GAC binding sites ($[\text{GAC}_{\text{bs}}]$) will scale with the amount of GAC used. In typical aquarium use, the amount of DOC will be relatively small and constant, and the amount of GAC used is the real variable available to the aquarist in terms of accelerating the removal of unwanted DOC's.

It will be our goal to calculate this value k under different conditions. The rate constant k is a function of all of the intrinsic features of the system, such as the flow rate through a Phosban Reactor, the physical configuration of the plumbing and Reactor, the dimensions and aspect ratio of the GAC bed, the GAC particle size and porosity, the diffusion rate to the GAC surface and along the GAC surface/pores as discussed earlier, etc. It is not possible at this level of analysis to deconvolute the calculated k value in terms of these specific parameters, but it is possible to use this

rate constant value for a given set of experimental parameters to calculate useful attributes of the system, such as (1) how long will it take to cut the amount of dye (or DOC) by 90% for a given tank size and GAC amount, and (2) how long will it take to saturate 90% the GAC binding sites with dye (or DOC's in a real aquarium) for a given tank size and GAC amount. These practical issues will aid in making informed decisions on the related questions of "How much GAC should I use?" and "When do I need to change my GAC?"

It is possible to derive a mathematical expression from Eq. (3) that relates the desired rate constant k to experimentally measurable (or derivable) quantities. This derivation can be found in any standard Chemical Kinetics treatment/textbook, and the expression is

$$(4) \quad \frac{1}{[GAC_{bs}]_0 - [dye]_0} \cdot \ln \left[\frac{[GAC_{bs}]_t / [GAC_{bs}]_0}{[dye]_t / [dye]_0} \right] = kt$$

where

t = time, in minutes

$[dye]_t$ = the concentration of dye, in moles/liter (M), at time t

$[dye]_0$ = the concentration of dye (M) at $t = 0$ (i.e., the beginning of the experiment)

$[GAC_{bs}]_t$ = the concentration of binding sites in the GAC, in moles/liter (M) at time t

$[GAC_{bs}]_0$ = the concentration of binding sites in the GAC (M) at $t = 0$

k = rate constant from Eq. (3), in $M^{-1}min^{-1}$

We can measure $[dye]_0$, the amount of dye that we put into the system in the beginning, and we can measure $[dye]_t$, the concentration of dye at some time t after the experiment begins. Obtaining the other necessary quantities, $[GAC_{bs}]_0$ and $[GAC_{bs}]_t$, requires some mathematical manipulation and some assumptions.

The total binding capacity of the GAC, which is equal to $[GAC_{bs}]_0$, can be indirectly measured by placing a known quantity of GAC in solution with a known and excess quantity of dye. The GAC will absorb the dye until it becomes saturated and can no longer bind any more dye. As a consequence, the concentration of the dye in solution will decrease as some of the dye is bound to the GAC. Eventually, the concentration of dye in solution will remain constant, as the now saturated GAC can no longer accept any more dye. We can monitor the decrease in dye concentration over time, and when the concentration levels out and no longer changes, we assume that we have reached the GAC saturation point. The difference in dye concentration between the initial value and this terminal value can be used to determine the amount of dye absorbed by the GAC, and we can use a mathematical treatment called a Langmuir isotherm to calculate the total binding capacity of the GAC for the dye. The mathematical form of the Langmuir isotherm is given in Eq. (5) [Potgieter, 1991]:

$$(5) \quad \frac{1}{x} = \frac{1}{x_m \cdot K} + \frac{1}{C} + \frac{1}{x_m}$$

where

x = milligrams (mg) of dye absorbed per mg of GAC, at equilibrium

C = the concentration of dye (mg/L), at equilibrium

K = a constant of no interest in this analysis

x_m = the total amount of dye (mg) that can be absorbed by 1 mg of GAC, at equilibrium

The total binding capacity of the dye is x_m , the quantity that we seek. Simply running several parallel trials to equilibrium, all differing in the amount of GAC used (leading to differing x values), and measuring the dye concentration, C , will provide the necessary data. Then, plotting $1/C$ vs. $1/x$ should provide a straight line whose Y-intercept is $1/x_m$. The desired quantity for this experiment, x_m , is then in hand.

In order to use this experimentally derived quantity of binding capacity, x_m , to calculate $[GAC_{bs}]_0$, we must define a new quantity, m , as the # of moles of dye that bind to one gram (abbreviated 1g) of GAC at equilibrium. Note that x_m originally is determined in units of mg of dye/mg of GAC, but that ratio is equivalent to gms of dye/gms of GAC. Thus, simply dividing x_m by the dye's molecular weight (MW, in g/mol) provides m :

$$(6) \quad m = \frac{x_m}{MW}$$

In addition, $[GAC_{bs}]_0$ requires knowledge of the system water volume (V) and the amount (mass) of GAC used (G):

V = the volume of the water in the system, in liters (experimentally measured)

G = the grams of GAC used (experimentally measured)

So, $m \cdot G$ = the total # of moles of binding sites for a given mass of GAC, and therefore

$$(7) \quad [GAC_{bs}]_0 = m \cdot G / V$$

In words, this expression indicates that the concentration of the total amount of GAC binding sites is equal to the total # of moles of binding sites divided by the system volume. As indicated earlier, the GAC binding sites are not evenly dispersed throughout the solution, but are confined to the GAC bed. This distinction is of no consequence, however, since our experimental protocol is equivalent to just adding a portion of GAC to the tank volume itself. The fact that dye can only be removed when the solution passes through the GAC bed is taken into account by the rate constant k .

In addition, it is convenient to formulate another definition:

$c = [dye]_t / [dye]_0$, which again is an experimentally measured quantity.

Substituting these two expressions into Eq. (4) leads to

$$(8) \quad \frac{1}{m \cdot G/V - [\text{dye}]_0} \cdot \ln \left[\frac{[\text{GAC}_{bs}]_t / [\text{GAC}_{bs}]_0}{c} \right] = kt$$

Arriving at a experimentally accessible expression for $[\text{GAC}_{bs}]_t$ is a bit trickier. We can start by noting that there is a fundamental mass balance expression that defines the removal of dye by GAC:

$$(9) \quad [\text{dye}]_0 - [\text{dye}]_t = [\text{GAC}_{bs}]_0 - [\text{GAC}_{bs}]_t$$

In words, this expression indicates that the amount of dye removed from solution up to a time t ($= [\text{dye}]_0 - [\text{dye}]_t$) must be equal to the amount of dye absorbed onto the GAC during that same time, which, in turn, must equal the decrease in the amount of GAC binding sites ($= [\text{GAC}_{bs}]_0 - [\text{GAC}_{bs}]_t$). Rearranging and substituting for $[\text{dye}]_t$ gives

$$(10) \quad [\text{GAC}_{bs}]_t = [\text{GAC}_{bs}]_0 - [\text{dye}]_0 \cdot (1 - c)$$

Substituting back into Eq. (8) then gives

$$(11) \quad \frac{1}{m \cdot G/V - [\text{dye}]_0} \cdot \ln \left[\frac{[\text{GAC}_{bs}]_0 - [\text{dye}]_0 \cdot (1 - c)}{c \cdot [\text{GAC}_{bs}]_0} \right] = kt$$

Substituting $[\text{GAC}_{bs}]_0 = m \cdot G/V$ and rearranging furnishes

$$(12) \quad \frac{1}{m \cdot G/V - [\text{dye}]_0} \cdot \ln \left[\frac{1}{c} - \frac{V \cdot [\text{dye}]_0 \cdot (1 - c)}{c \cdot m \cdot G} \right] = kt$$

which simplifies to

$$(13) \quad \frac{1}{m \cdot G/V - [\text{dye}]_0} \cdot \ln \left[\frac{1}{c} - \frac{V \cdot [\text{dye}]_0}{m \cdot G} \left(\frac{1}{c} - 1 \right) \right] = kt$$

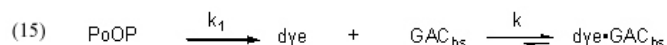
The quantities m (derived from the Langmuir isotherm experimental data) and $[\text{dye}]_0$ are measured initially, and remain constant throughout all of the experiments. The amount of GAC, G , is measured at the beginning of each experimental run, and $[\text{dye}]_t$ (from which c is derived) is measured at different times t . The quantity on the left-hand side of Eq. (13) is graphed against time t , and the slope of that line is k , the desired quantity.

It will be valuable to define a new quantity, t_{90} , as the length of time required to reduce a given starting dye concentration by 90%. The t_{90} value can be extracted from Eq. (13) by setting $c = 0.1$ ($= 90\%$ depletion of the dye concentration), and solving for t :

$$(14) \quad t_{90} = \frac{1}{k(m \cdot G/V - [\text{dye}]_0)} \cdot \ln \left[10 - \frac{9V \cdot [\text{dye}]_0}{m \cdot G} \right]$$

This Case (1) mathematical modeling ultimately can be applied to answering the question, "How much GAC should I use?" (see Section 3.1). That is, this model will have the most utility in a situation where GAC has not been used before, and the DOC level in the water has built up, or a situation where the tank has been medicated, and so there is a specific level of impurity (excess medication) that must be removed quickly.

To address the Case (2) scenario, where GAC is used continuously and DOC (modeled by dye) is continuously being added to the water, we must explicitly incorporate a DOC source into the simple expression Eq. (1). Specifically, we can allocate that role to PoOP (Precursors of Organic Particulates), and then assign a generic rate constant k_1 to describe the overall rate of conversion of PoOP into DOC's (modeled by dye in Eq. (15)). This simplistic model allows for a continuous and gradual introduction of DOC's (dyes) into the water column of an aquarium as a consequence of a wide range of biological processes that degrade the PoOP into soluble organic material. Thus, Eq. (15) illustrates how dye (as a model for DOC) is both formed from PoOP with a rate constant k_1 , and removed by the GAC with a rate constant k , as previously discussed.



Surprisingly, the expansion of Eq. (1) into Eq. (15), which includes the dye generation term, renders the kinetics mathematically unsolvable, at least in terms of arriving at an analytical solution like that expressed in Eq. (13). This problem has long been recognized, and Chien has developed a workaround using mathematical approximations (Bessel functions) that are applicable if certain criteria are met (Chien, 1948). However, there are two factors that mitigate against using the Chien formalism to solve this problem:

1. It is not clear whether the criterion for its use, which involves the relative magnitudes of k and k_1 , is met.
2. We can only guess at the concentration of PoOP and the value of the rate constant k_1 (necessary inputs for Chien's mathematical model).

This second point is really a critical one, as it will cloud any attempt to arrive at a solution based on Eq. (15). However, all is not lost, as there is another approach to solving kinetic (rate) expressions that is applicable in this case; kinetics simulations. It is possible to use one of the commercially available kinetics modeling programs to make guesses for $[\text{PoOP}]$ and k_1 , and then calculate desirable quantities like $[\text{GAC}_{bs}]_t$ or $[\text{dye}]_t$ based on experimentally determined k values (from the Case (1) math and experimental measurements). Even with this approach, we must have some basis for making guesses about $[\text{PoOP}]$ and k_1 , and fortunately, we do. As discussed later in more detail, we have measured the concentration of oxidizable organics in the water of several reef tanks, and so we have an idea of the steady-state concentration, $[\text{DOC}]$, in an actual GAC-treated tank. With that constraint, we can then adjust the product $[\text{PoOP}] \cdot k_1$ in the kinetics simulation program to hold $[\text{DOC}]$ within a realistic range. That is, the rate of DOC removal will be measured experimentally, and then we just have to balance that rate of removal with a rate of DOC introduction via a $[\text{PoOP}] \cdot k_1$ quantity that keeps the overall DOC level around the steady-state values measured in actual marine tanks. For these studies, we use the shareware program KinTekSim (<http://www.kintek-corp.com/members/>).



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THE EXPERIMENTAL VARIABLES

The experimental variables examined in this study are:

1. The type of GAC: Two Little Fishes Hydrocarbon and Marineland's Black Diamond.
2. The flow rate: 49 gph (= 0.81 gpm) and 72 gph (= 1.2 gpm).
3. The amount of GAC: 6.25 g/gal up to 50 g/gal.
4. The dye molecule probes. This latter experimental variable is quite important to the success of these experiments, and so some more elaboration and a few digressions are in order. First, a digression about the pros and cons of model use in science:

Some scientific disciplines have a "look but don't touch character" to their experimentation. For example, cosmology and paleontology ask questions about events so distant in time (the birth of the Universe or the behavior of dinosaurs) that it is impossible to construct real-time experiments to gain hard data. Thus, model building and model testing are the primary experimental tools of these types of disciplines. Other fields of science are readily probed by direct experiment, like chemistry and biology. However, even within these hands-on sciences, the type of experiments, and the quality of data retrievable, varies significantly. For example, directly probing a biological or chemical system of interest is possible, but sometimes the system is so complicated that the data obtained is uninterpretable or compromised. For example, such a situation might pertain to the question of what, exactly, is GAC removing. Sure, it can be labeled as "DOC", or "marine humic substances", but those categories reveal nothing about its chemical structure and hence its reactivity with GAC or any other component of an aquarium. In reality, the DOC is so complex and so heterogeneous that it would be a Herculean analytical task to try to determine its constituents and their relative amounts. So, how can experiments whose goal involves DOC chemistry be performed? In principle, it might be possible to isolate and concentrate DOC, and use that preparation as an experimental starting point without ever knowing its composition. That type of procedure would hew closest to the goal of performing experiments on a "real" system, but the downsides of this approach are many: there is currently no effective way to isolate all of the DOC's, although some subset of DOC components can be isolated; there is no effective way to ensure that whatever might be isolable actually corresponds to the DOC of an aquarium; there is no way of testing whether the DOC isolated from one aquarium is similar to, or different from, the DOC isolated from another aquarium. In light of these types of technical (but not conceptual!) problems in working with complex "real" systems, scientists often turn to simplified model systems that presume to capture the essential elements of the real system but reduce the experimental variables to a manageable number. In this approach, experiments can be designed and executed, but the real challenge lies in choosing appropriate model systems that can give insight into the real system. In the case of GAC and DOC removal studies, several authors used a blue dye, the Salifert test kit reagent methylene blue (1), as a model for organic impurities that might be found in a reef tank (Cerreto, 2006; Schiemer, 1997). Harker, on the other hand, used the yellow exudates from stewed seaweed as a model for DOC,

reasoning that (a) it was yellow in color like DOC, and (b) it was derived from a marine source (Harker, 1998). In actuality, both approaches share both the strength of the reductionist approach by defining a system upon which useful experiments can be performed, and its weaknesses by assuming that some model compound(s), known in the case of the Salifert test kit, and unknown in the case of the Harker experiment, accurately mimic the constituents of DOC with respect to their interactions with GAC.

With these thoughts as background, we chose our models for DOC by asking the following question: what are the likely types of components, at least as broad classes, in DOC, and what commercially available dye molecules might have similar chemical and/or structural characteristics to these components? The premise underlying this approach to model system selection is that if the chosen dyes share chemical/structural characteristics with some of the presumed DOC components, then perhaps their diffusion properties and chemical interactions with the chemically active sites in GAC might be similar to those of the actual DOC components. As a starting point for this analysis, it is worth noting that the chemical composition of both bacterial and mammalian cells can be averaged to give the following values (Alberts, 2002):

- Proteins: 50 - 60%
- Lipids: 7 - 17%
- Nucleic acids: 5 - 23%
- Oligosaccharides: 7%
- Small metabolites: 10%

Some illustrative examples from each class of biomolecule are given in Figure 1. Proteins, nucleic acids and oligosaccharides are polymers (= large molecules composed of many linked small molecule repeat units; beads on a string is an apt analogy) whose sizes range from millions of repeat units (nucleic acids) to hundreds of repeat units (proteins) to tens of repeat units (oligosaccharides). Lipids and metabolites, on the other hand, are discrete small molecules that are not built up from joining repeat units. The category "metabolites" actually is an all-encompassing class that includes many organic molecules (vitamins, hormones, enzyme co-factors, etc.) that are diverse in structure and chemistry. The chlorophyll molecule (Figure 1) was chosen as an example because of its obvious color, and because it is representative of a class of small metabolites called porphyrins that are both highly colored and ubiquitous in living organisms (hemoglobin, myoglobin, many enzyme co-factors). As cells are ruptured and the contents are released, these "molecules of life" become food for bacteria, whose metabolic processes function to both chop up polymers to their individual repeat units and also to modify the basic chemical structures of the components, typically by oxidation. In this way, these species serve as carbon-based fuels whose ultimate fate, in many cases, is conversion to CO₂. However, not all molecules are susceptible to complete oxidation to form CO₂, and some of the organic residues are chemically inert to further oxidative or degradative action by bacterial enzymes. In this case, the waste material cannot be further modified, at least at an appreciable rate, and so it accumulates. This leftover organic trash is part of what we call dissolved organic carbon, DOC.

With this information as background, we can now ask, "What type of dye molecules might resemble, in structure and/or chemical functionality, elements of DOC?" This question, of course, is impossible to answer with precision for the reasons discussed above, but we can make some educated guesses as to what type of chemical units might survive intact, or be formed from, the input species of Figure 1. The fact that DOC is soluble (= dissolved) requires that it contains functional groups which are hydrophilic (= water loving). In addition, the nucleic acids and some of the proteins' individual amino acid components (e.g., histidine) contain flat 5- and 6-membered nitrogen-containing ring units that are generally resistant to chemical transformation. Therefore, choosing a dye that contains both flat nitrogen-containing rings and water solubilizing charges seems appropriate. This line of reasoning led to the inclusion of Basic Blue 3 (7) in our study,

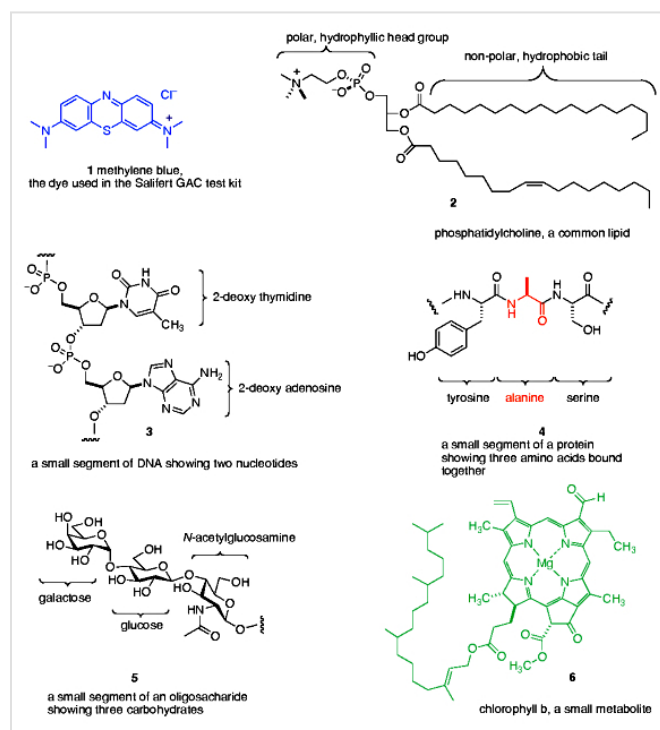


Figure 1. Examples of the molecules of life, and methylene blue, the Salifert GAC test kit reagent.

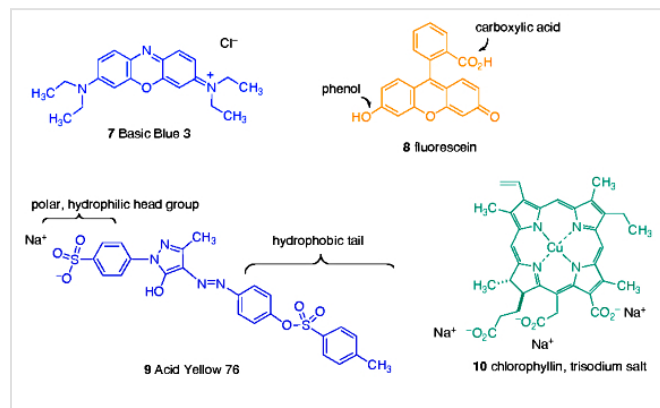


Figure 2. The dyes used in the GAC-based adsorption assays.

Figure 2. This dye is structurally similar to methylene blue (1) from the Salifert test kit.

The inevitable oxidation and chemical condensations that define much of the pathway from cell metabolite to DOC typically results in the formation of compounds featuring condensed ring systems, and also to the generation of oxidized chemical functionality like carboxylic acids and phenols. One dye that embodies both of these likely DOC characteristics is fluorescein (8), Figure 2. This orange dye might be a simple model for the "humic substances" that contain acids and phenols on rings similar to the presentation depicted in the structure 8.

Many organic molecules of the type produced by biological metabolism have a dual character with respect to water. These molecules have both a hydrophilic portion and a hydrophobic (= water hating) portion, and they are termed amphoteric. Lipids are good examples of amphoteric molecules, as illustrated in Figure 1. In particular, amphoteric molecules might be good candidates for removal by GAC, as the hydrophilic portion will keep them in solution, whereas the hydrophobic portion is similar in character to the binding surface of GAC and therefore is susceptible to strong association. The dye molecule Acid Yellow 76 (9) has just such amphoteric character, as it has both a hydrophilic, charged sulfonate group and a carbon-rich and uncharged tail (Figure 2). In addition, the 6-membered ring residues in 9 are

characteristic of many biological metabolites, and this very stable and unreactive ring often survives bacterial action either intact or only slightly modified. Thus, it may serve as a useful model for amphoteric molecules in DOC.

Finally, the common occurrence of porphyrin-based metabolites in cells, and the relative resistance of the porphyrin superstructure to complete degradation (porphyrins are used as biomarkers in geological samples millions of years old (Callot, 2000)), suggests that a dye mimicking this color source might be a useful contributor to modeling DOC in GAC-based removal studies. Towards this end, the porphyrin derivative chlorophyllin (10) was selected as the final probe dye for use in the GAC studies.

These model compounds were chosen for their resemblance to presumed DOC components, although this point cannot be experimentally verified. Argument-by-analogy will be our strongest ally upon employing this modeling approach to investigating GAC's properties. Thus, using these model compounds will allow us to acquire meaningful data and provide a framework for interpretation of the results, which in turn will, hopefully, provide some guidance for the aquarist contemplating the details of GAC use in his/her aquarium.

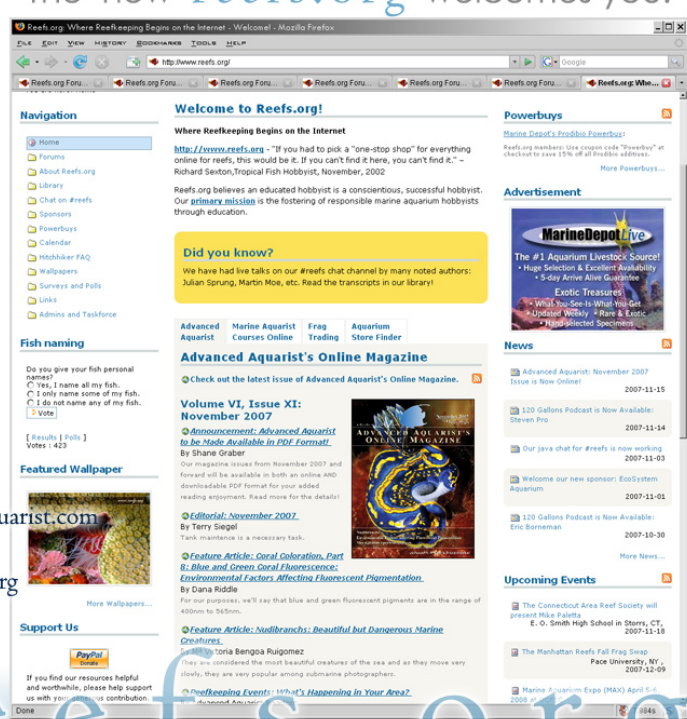
In Part 2 next month, we will continue with the Results and Discussion of the data.



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FEATURE ARTICLE

MONTIPORA DIGITATA: A STONY CORAL FOR ALL HOBBYISTS

By Dana Riddle

These animals are generally hardy in captivity and can grow rather quickly, making them attractive to beginning and intermediate reefkeepers.

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This *Montipora* species is a good choice for those hobbyists wanting to make the jump to small-polyp stony (SPS) corals. Their appearance is soft and velvet-like when their polyps are extended. These animals are generally hardy in captivity and can grow rather quickly, making them attractive to beginning and intermediate reefkeepers. *Montipora digitata* specimens can lend a numbers of colors to an aquarium, as they can be brown, orange, purple, pink or a combination of colors. The single-color specimens are usually readily available and relatively inexpensive. Unusually colored specimens are often in high demand and command premium prices. In short, *M. digitata* is a coral that can be appreciated by beginning and advanced hobbyists.

Common Name: Velvet Coral

Family: Acroporidae

Genus: *Montipora* (L. - mons- mountain, and pora - pore; describing elaborations and porous nature of the corallum).

Species: *Montipora digitata*, which can be confused with *M. samarensis*.



Geographical Range and Common Habitat: Shallow waters of the Indo-Pacific and Red Sea.

Growth Forms: Colonies are digitate (finger-like) or arborescent (tree-like) with branches that may fuse together (technically called anatomosing branching).

Known Symbionts: Zooxanthellae (*Symbiodinium* sp.) including any one of the following: Clade* C1 (a 'generalist' clade with ability to adapt to a wide variety of depths and light conditions), or C15 (thermally-tolerant), or Clade C73 (from shallow water, and possibly an example of a clade co-evolving with this *Montipora* species).

*A 'clade' is a grouping of organisms based on phylogenetic similarities while sharing a common ancestor.

LIGHT REQUIREMENTS

Zooxanthellae photosynthesis is dependent upon many factors, and lighting is an important link in this chain of factors. Providing sufficient lighting while ignoring other parameters (such as water motion and water chemistry) can result in low rates of photosynthesis. Details of these other factors are detailed below. With this in mind, let's begin our look at types of zooxanthellae known hosted by *M. digitata*.

In order to understand the lighting requirements of *M. digitata* specimens, we should examine the types ('clades') of symbiotic dinoflagellates found within their tissues.

There are 3 clades known to infect *M. digitata*, one of these is a 'generalist' zooxanthellae tolerant of high and low light. C15 is noted as being tolerant of higher temperatures. Little is known about Clade C73 other than it seems to be found only in *Montipora digitata* specimens from shallow water (LaJeunesse, 2005).

It is assumed that *Montipora digitata* specimens harbor only one zooxanthella clade at a time - there is no contrary evidence to my knowledge. However, current technology used to genetically fingerprint zooxanthellae do not 'see' clades when their numbers are only 5% or so of the total population. If *M. digitata* contains two or more clades, then 'reshuffling' (where one clade becomes dominant, but temperature and other factors could play a role)

according to environmental conditions (most likely lighting - either due to depth or seasonal changes) could explain the host's abundance. Vertical zonation (where light is rapidly attenuated with increasing depth) is thought to be explained by the type zooxanthellae hosted by the coral animal (Iglesias-Prieto et al., 2004).

This listing is presented under the presumption that each of these zooxanthellae clades has a genetically-imprinted photoadaptation range and is the dominant symbiont; hence the following groupings of corals would probably do well under the same lighting regime as long as other environmental conditions are correct.

C1: Clade C1 is considered a 'generalist' zooxanthellae in that it infects a large number of coral genera hosts in the Pacific as well as the Atlantic, and is distributed over a wide variety of depths. Thus, corals containing this clade could be considered highly adaptive to light intensities. They can tolerate high light but are probably best suited for lower light intensities. Clade C1 (along with C3, C21, C3d, C1c and C45) is believed to be an ancestral type from which other clades evolved (LaJeunesse, 2004). If we subscribe to the theory that all C1 zooxanthellae have the same photoadaptive capabilities, then these photosynthetic animals would do well under the same lighting conditions: *Acropora cervicornis* (Baker et al., 1997), *Acropora divaricata*, *A. humilis*, *A. hyacinthus*, *A. longicyathus* (from the GBR; van Oppen et al., 2001), *Acropora palifera* (from Taiwan, Chen et al., 2005), *Acropora sarmentosa*, *A. tenuis* (GBR; Van Oppen et al., 2001), *Astreopora* (GBR, LaJeunesse et al., 2003), *Astreopora myriophthalma* (Taiwan; Chen et al., 2005), Caribbean anemones *Bartholomea* and *Condylactis* spp. (LaJeunesse et al., 2003), Great Barrier Reef 'corallimorpharia' and *Coscinaraea*, *Coscinaraea wellsii* and *Cycloseris vauhani* from Hawaii (LaJeunesse et al., 2004), *Cyphastrea* (LaJeunesse et al., 2003), *Cyphastrea chalcidicum* (van Oppen, 2005), Atlantic and Pacific *Discosoma* spp. (LaJeunesse, 2005), *Echinophyllia orpheensis*, *Echinophyllia lamellosa* (Chen, 2005), Caribbean *Eunicea* (LaJeunesse et al., 2003), *Euphyllia ancora*, *Euphyllia glabrescens* (Chen, 2005), *Favia* (LaJeunesse et al., 2003), *Favia fava* and *Favites abdita* from Taiwan (Chen, 2005), *Fungia* (LaJeunesse et al., 2003), *Fungia crassa* (van Oppen, 2005), *Galaxea*, *Goniastrea* (LaJeunesse et al., 2003), *Goniastrea rectiformis* (Chen, 2005), *Goniopora* (LaJeunesse et al., 2003), *Goniopora columba*, *Goniopora lobata* (Chen, 2005), *Herpolitha*, *Hydnophora* (LaJeunesse et al., 2003), *Hydnophora excessa* (Chen, 2005), *Icilogorgia*, *Lebruna*, *Leptastrea* (LaJeunesse et al., 2003), *Leptoria phrygia* (Chen, 2005), *Leptoseria incrustans* (LaJeunesse, 2004), *Linuche*, *Lobophytum*, *Merulina* (LaJeunesse et al., 2003), *Merulina ampliata* (Chen, 2005), *Merulina scrabacula* (van Oppen, 2005), *Millepora* sp. (LaJeunesse et al., 2003), *Montipora aequituberculata* (Chen, 2005), *Montipora cactus* from Indonesia (van Oppen, 2004), *Montipora cactus*, *Montipora curta* from Taiwan (Chen, 2005), *Montipora confusa* (van Oppen, 2004), *Montipora effluorescens*, *Montipora hispida*, *Montipora* sp., *Montipora spongodes*, *Montipora undata* from Taiwan (Chen, 2005), *Mycedium* (LaJeunesse et al., 2003), *Mycedium elephantotus* (Chen, 2005), *Pachyseris*, *Paulastrea*, Caribbean *Palythoa*, Hawaiian *Palythoa* (LaJeunesse et al., 2003), *Pavona desucata*, *Pavona frondifera*, *Pavona varians*, *Pavona venosa* (Chen, 2005), the 'bubble' coral *Plerogyra* (LaJeunesse et al., 2003), *Plesiastrea verispora* (Chen, 2005), gorgonians *Plexaura* and *Plumigorgia* (LaJeunesse et al., 2003), Taiwanese *Pocillopora damicornis* (Chen, 2005), *Polyphyllia*, *Porites* sp. (LaJeunesse et al., 2003), shallow-water *Porites cylindrica*, *Porites lutea*, *Porites solida* (from

Taiwan; Chen, 2006), GBR *Psammocora* (LaJeunesse et al., 2003), *Pseudosiderastrea tayamai* (Chen, 2005), *Rhodactis*, *Rumphella*, *Sarcophyton*, Pacific *Scolymia*, *Siderastrea*, *Sinularia* (LaJeunesse et al., 2003), *Stylocoeniella guentheri* (Chen, 2005), *Stylophora* sp. (LaJeunesse et al., 2003), *Stylophora pistillata* (Chen, 2005), a giant clam (*Tridacna* sp.), *Turbinaria* sp. (LaJeunesse et al., 2003), *Turbinaria mesenteria* (Chen, 2005), Pacific and Caribbean *Zoanthus* spp. (LaJeunesse et al., 2003).

C15: Limited to the Indo-Pacific and considered thermally tolerant and often found in *Porites* corals. It is often found in Pacific *Porites* spp., though obviously not exclusive of other genera. For instance, C15 is also found in *Aglaophenia*, *Heteroxenia* (western Pacific, both sampled at 1.0 -15m LaJeunesse et al., 2003), *Montipora* (GBR, Pochon, 2004), *Pocillopora damicornis* (0.3-8.0m, Kenya, Visram and Douglas, 2006), *Porites* sp. from various Pacific locations (LaJeunesse et al., 2003 and Pochon et al., 2004), *Porites brighami* (at 20m in Hawaii, LaJeunesse et al., 2003); *Porites compressa* (Hawaii, 15-25m, LaJeunesse et al., 2003), *Porites cylindrica* (GBR, LaJeunesse et al., 2003), *Porites evermanni* (now *P. lutea*, Hawaii, 5.0-20.0m, LaJeunesse, 2004), *Porites lobata* (Hawaii, 2-20m, LaJeunesse, 2003), *Porites lutea* (purple variant, 1.5m, Hawaii, LaJeunesse et al., unpublished). C15 is possibly a variant of Clade C3 (LaJeunesse, 2005).

(As a footnote, a Hawaiian *Porites compressa* specimen was transplanted from depth to about 1m - it retained its C15 zooxanthellae even years after the move. What does this suggest about fidelity of a particular zooxanthellae clade to its host coral?)

PAM fluorometry work found onset of photosaturation ranging from 250-400 $\mu\text{mol} \cdot \text{m}^{-2} \cdot \text{sec}$ (~12,500 - 20,000 lux) and onset of photoinhibition ranging from ~350 to ~750 $\mu\text{mol} \cdot \text{m}^{-2} \cdot \text{sec}$ (~17,500 - 37,500 lux) in a Hawaiian *Porites lobata* and *Porites lutea* specimens, respectively (ITS 2 'DNA fingerprinting' analysis on *P. lutea* by LaJeunesse et al., unpublished; PAM fluorometry by Riddle, unpublished).

C73: Apparently found only in *Montipora digitata* specimens in very shallow water (0.5m, Eastern Pacific, LaJeunesse et al., 2003).

AQUARIUM LIGHTING CONDITIONS

I've been fortunate in having had the opportunity to view many reef aquaria across the country. On many of these trips, I carried a PAR meter (a Li-Cor 189 with cosine-corrected submersible sensor) with me and collected the following information.

Orange *M. digitata* specimens were observed to be tolerant of a wide range of lighting conditions (up to 700 $\mu\text{mol} \cdot \text{m}^{-2} \cdot \text{sec}$ in one instance) but did well in lower light intensity ranging from 144 $\mu\text{mol} \cdot \text{m}^{-2} \cdot \text{sec}$ (provided by an Iwasaki 400w 6500K metal halide lamp), to 150 $\mu\text{mol} \cdot \text{m}^{-2} \cdot \text{sec}$ (PFO LEDs; see Figures 2-5) to 200-223 $\mu\text{mol} \cdot \text{m}^{-2} \cdot \text{sec}$, and, finally, 565 $\mu\text{mol} \cdot \text{m}^{-2} \cdot \text{sec}$.

Purple specimens were less common than orange ones. PAR values for successful maintenance of this variant was seen at 240-265 $\mu\text{mol} \cdot \text{m}^{-2} \cdot \text{sec}$ (generated by a 175w 6500K metal halide lamp and actinic-white VHO fluorescent lamps).

A green *M. digitata* was doing well at a light intensity of 240 $\mu\text{mol} \cdot \text{m}^{-2} \cdot \text{sec}$ (produced by a 175w 6500K metal halide and

actinic-white VHO fluorescent lamp combination). Another green specimen was seen in light intensity of $550 \mu\text{mol}\cdot\text{m}^{-2}\cdot\text{sec}$.

Blue and pink specimens were not common. The former was growing (and maintaining coloration) at $200 \mu\text{mol}\cdot\text{m}^{-2}\cdot\text{sec}$ (a 400-watt Venture 'daylight' metal halide lamp) and the latter was doing nicely at $360 \mu\text{mol}\cdot\text{m}^{-2}\cdot\text{sec}$.

Note: For those having a submersible lux meter, be aware that it is possible to convert PAR to lux. Each lamp will have a different conversion factor, but a very general rule of thumb is to divide lux by 50 to arrive at a crude estimate of PAR.

WATER MOTION

Water motion is difficult to quantify so most hobbyists must rely upon visual indicators, with polyp expansion and movement probably the most common. Interestingly, too much and too little water motion can cause corals to retract polyps. Too much will of course deform the polyp and perhaps cause shearing or tearing of soft tissues. On the other hand, a coral can recognize too little flow and after a prolonged period of little water movement, it realizes it is not catching any food and will retract polyps in order to conserve energy (Sebens, 1997). (Too much lighting will also cause some corals to contract their polyps to protect themselves and their zooxanthellae from excessive light. This is sometimes indicated by expansion of shaded polyps while those exposed to light are retracted.)

Fortunately, providing sufficient water motion is not the challenge it once was. Some of the newer propeller pumps on the market can potentially provide sufficient water movement along with low electrical consumption (see Riddle, 2007 for details).

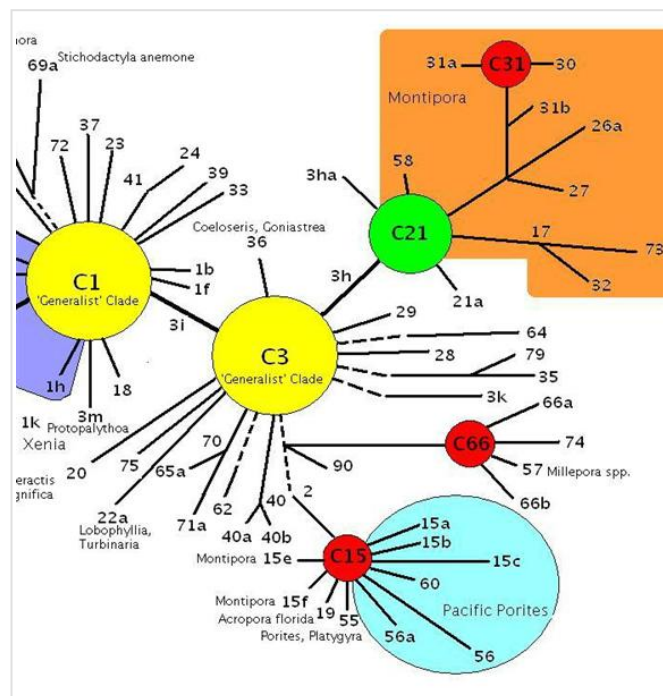


Figure 1. A diagram depicting adaptive radiations of zooxanthellae clades. *Montipora digitata* specimens are known to contain C1 (generalist), C15 (resistant to high temperature) and C73 clades. Note - the orange shading represents clades found only in *Montipora* species, although some are descended from clade C15. After LaJeunesse 2005.

Correct water motion is indicated by polyps gently rocking in the currents.

GROWTH SEQUENCE

The following photos (Figures 2 -5) show growth of a *Montipora digitata* over the course of 12 months.



Figure 2. The epoxy holding this coral to the substrate has barely cured on Day 1.



Figure 3. Ninety days after arrival. The coral has adapted to its new home and is starting to encrust its base as well as extend its branches.



Figure 4. Who says SPS corals can't grow under LED lamps? This one is (and many others are) at a light intensity of $150 \mu\text{mol}\cdot\text{m}^{-2}\cdot\text{sec}$.

OTHER PARAMETERS

Hobbyists should pay close attention to calcium and alkalinity concentrations. Calcium, of course, is important for skeletal growth, and concentrations should be maintained in the 400-450 mg/l range. Alkalinity (reported as CaCO_3) is very important as well - it is the inorganic carbon source for photosynthesis and is also used for skeletal growth. Alkalinity should be maintained at 160 mg/l or ~ 3.25 meq/l. Addition of bicarbonates (in the form of any of the commercially-available 'alkalinity boosters') may promote growth in corals even in the presence of relatively high nutrient concentrations (Marubini, 1999).

COLORATION

Velvet corals can be very colorful, with blue, green, orange, pink (sometimes called 'super purple' or 'rose') and purple colonies



Figure 5. Lateral branching has slowed, with most growth seen at the coral's base. Some branches have been accidentally broken off during routine tank maintenance.



Figure 6. The Superman digitata (although its irregular shape and thin branches suggest it is possibly *M. samarensis*). It is an attractive animal, no matter what the identification. Photo courtesy Steven Reyes.

(sometimes referred to as 'grape') being quite common, in addition to the brown morphs.

Orange colonies can sometimes become pinkish when maintained under intense lighting (probably due to loss of photopigments when zooxanthellae bleach). Orange and green coloration is almost certainly due to fluorescent pigments within the coral tissues. There are two types of fluorescent pigments that could cause the orange coloration - the first is a fluorescent protein (Fluorescent Pigment, or FP 575; the maximum fluorescent emission is 575nm - reddish-orange); the other is a photopigment (phycoerythrin) found in cyanobacteria living in symbiosis with the coral host (Mazel et al., 2004). The spectral signature of the fluorescent emission of FP-575 and phycoerythrin are practically identical and the emission's shape will not distinguish between the two.

'Rose' and purple colorations are probably due to non-fluorescent chromoproteins. These pigments (assuming they are indeed distinct from one another) appear as they do since they preferentially reflect red and blue wavelengths. The status of the blue pigment is, to me, uncertain. It could be either fluorescent or non-fluorescent.

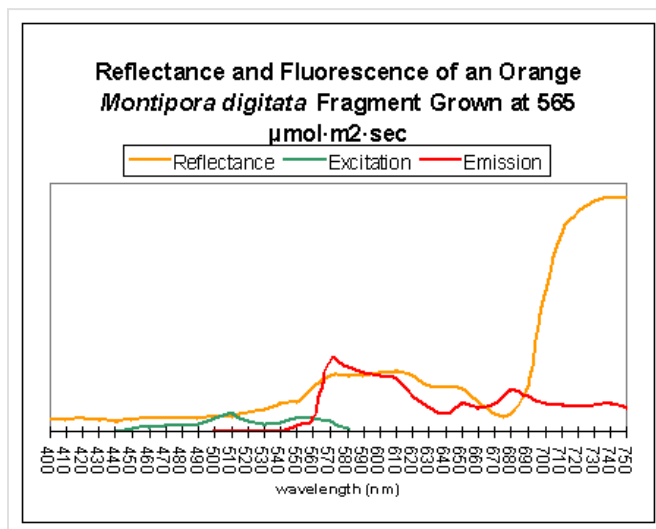


Figure 7. An example of fluorescence influencing apparent coloration. A fluorescent pigment, with maximum emission at ~ 575 nm, lends an orange-red color to the light reflected by the coral. The fluorescent pigment is maximally excited by green light at about 508nm. Mazel, unpublished data, from an aquarium specimen supplied by the author.

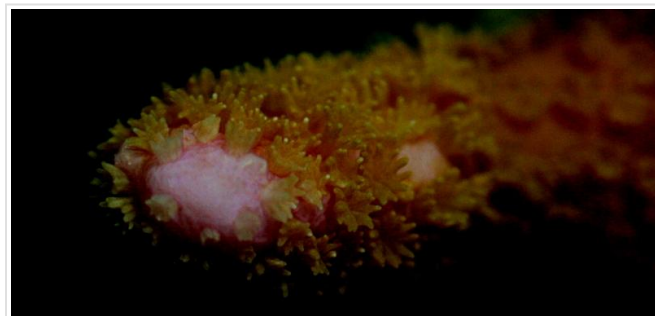


Figure 8. This *M. digitata* variant contains a non-fluorescent purple chromoprotein.

COLORATION AND DOMINANCE

Interestingly, differently colored corals we identify as *M. digitata* can be (but are not always) highly competitive. The lowly brown morph can be attacked and their tissues destroyed by purple, orange and green morphs. Those specimens colored forest green are dominant over the other three morphs, but orange *digitatas* beat up on purple ones. We have to wonder why these corals of the same species do not always recognize each other as 'self' (perhaps DNA fingerprinting will someday tell us these coral morphs are different species). For the moment, realize that these corals can be competitive, so place them with plenty of room for growth.

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FEATURE ARTICLE

CORAL COLORATION, PART 9: TRIDACNA AND OTHER PHOTOSYNTHETIC CLAM COLORATION, WITH OBSERVATIONS ON POSSIBLE FUNCTIONS

By Dana Riddle

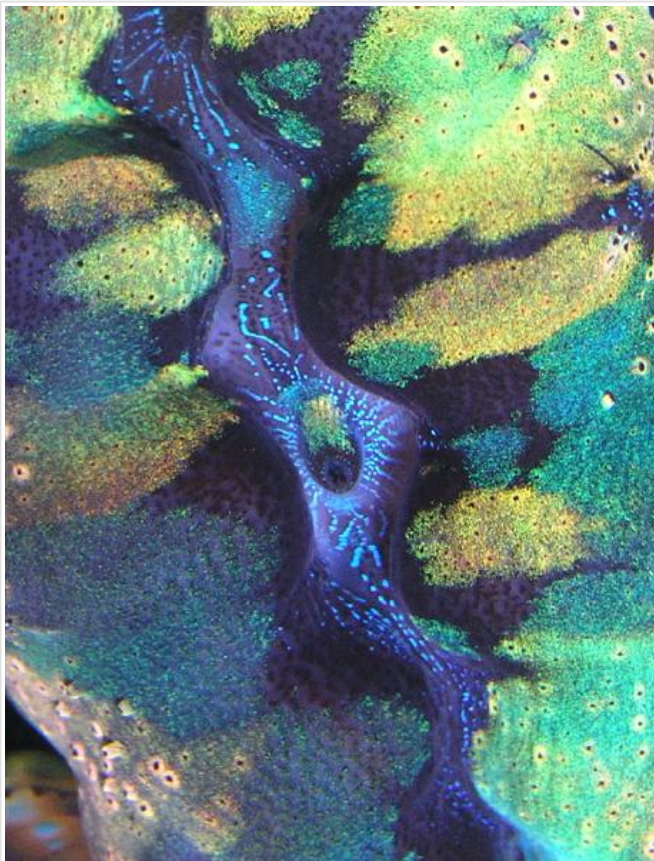
This month, we will continue our observations of marine invertebrate coloration with a slightly different subject - that of the impressive appearance of photosynthetic clams.

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With full realization that I'll get email stating that 'clams are not corals', I can not be content to leave it at that. So, I will make an even bolder statement - *Tridacna* clams' tissues (along with certain other genera) are colorless and contain no spectacular pigments. You are paying good money for an optical illusion. But what an illusion!



This month, we will continue our observations of marine invertebrate coloration with a slightly different subject - that of the impressive appearance of photosynthetic clams (mostly *Tridacna* and *Hippopus* species, but also including *Fragum*, and *Corculum* specimens). Strangely enough, and contrary to information in many hobbyist references, these clams do not contain colorful pigments. The 'metallic' iridescent colors we often see are caused by light reflected from tiny internal structures. Also involved are refraction, light interference and possibly diffraction. To understand why these colors are apparent necessitates a review of a few optical physics terms.

DEFINITIONS AND EXAMPLES

Coral coloration (due to reflection and fluorescence) is relatively simple when compared to the science involved with clam coloration. Take a deep breath, and we'll get started.

Diffraction: Bending of light waves around an object. The colorful surfaces of CDs and DVDs are good examples of diffraction.

Hue: One of three attributes of color (along with chroma and lightness). This attribute is described with names such as 'red', 'yellow', etc.

Interference: A characteristic of light waves under certain circumstances to reinforce or cancel hue. Reinforcement is called 'constructive' interference while cancellation is called 'destructive' interference. Interference is caused by light waves traveling at different speeds and staying in or out of phase. If the light beams are of the same orientation after reflection/refraction, no color will be apparent. However, certain colors will be amplified if beams are out of phase (within a very small range).

An example of interference can be seen when two pebbles are dropped into a tub of water. Some waves will combine and become larger while others' energies meet and 'cancel out.' Basically, the same thing can happen with light waves during constructive or destructive interference.

The colors of soap bubbles or oil on water (and *Tridacna* iridescence) are due to constructive and destructive interference (See Figure 1).

For a tutorial on interference, see:

<http://www.glenbrook.k12.il.us/gbssci/phys/class/waves/u10l3c.html>

Iridophore: For our purposes, iridophores are the iridescent patches of color scattered across the mantle of *Tridacna* clams. An iridophore consists of numerous smaller bodies or cells called *iridocytes*. In turn, iridocytes contain uniform, regularly spaced stacks ('lamine' *iridosomes*) of sulfur-rich protein called *iridosomal platelets*. See Figure 2.

Iridophores and their various substructures have been described in *T. maxima* (Fankboner, 1971; Farmer et al., 2001; Kawaguti, 1966); *T. gigas* (Griffiths et al., 1992); *T. crocea* (Griffiths et al., 1992); *T. squamosa* (Fankboner, 1971); *Hippopus hippopus* (Griffiths et al., 1992); and *T. tevoroa* (Klump and Lucas, 1994). It is believed other photosynthetic clams contain them as well.

Note that clam iridophores are made of different proteins than many other animals' iridophores. For instance, cephalopod (squid, octopus, etc.) iridophores are based on a different material (guanine, which is why their iridophores are sometimes called *guanophores*. If that sounds a little odd - it is. Guanine was originally isolated from guano, or bird poop. This little known fact can make you the life of the next black tie cocktail party you attend...and make you wonder about the motivation of some scientists!).

Iridescence: An optical phenomenon in which hue ('color') changes with the viewing angle.

Reflection: The 'return' or 'bouncing back' of light waves, sometimes (but not always) without alteration of the light and incident angle.



Figure 1. A common example of interference. These bubbles do not, nor do *Tridacna* clams, contain pigments that make them iridescent. Light reflected from the inside and outside surfaces of the bubble recombine and, if out of phase, cause constructive interference and different hues. If in phase, no color is apparent due to destructive interference.

Refraction: Deviation or 'bending' of light waves as they pass from one medium to another of different optical density. The amount of 'bending' caused by a material is called its refractive index.

Mirages are due to refraction caused by layers of cool and warm air.

Schemochromes or 'Structural Colors': Those colors caused by presence of tiny light-reflecting structures and optical physics such as refraction, interference and others. *Schemochromes* are the opposite of *biochromes* (which contain true colored pigments). Therefore, schemochromes are not actually pigments but only an optical illusion caused by structural properties (and widely seen in many bird feathers, reptile and fish scales and tissues, insects and marine invertebrates).

To stitch this information together - the 'metallic', iridescent colors displayed by *Tridacna* and other taxa are not true pigments (*biochromes*) - they are *schemochromes*. Schemochromes are due to physical structures within tissues. In the case of colorful clams, these structures are called iridophores. Iridophores contain uniform, protein-rich cells called *iridosomal platelets*. When light strikes the iridosomal platelets, it is reflected but not without modification. The color reflected is dependent upon the refractive index of the protein, its orientation, number of platelets in the stack, angle of illumination and other factors. Thus, light falling upon the platelets is refracted (due to different optical densities). Construction and destructive interference now come into play. Again, depending upon the refractive index and possibly the orientation of the proteins, interference can reinforce certain colors, or cancel them. These refracted/reflected



Figure 2. *Tridacna* reflective (and refractive/diffractive) proteins are arranged in neat rows. After a photomicrograph by Griffiths et al., 1992.

light waves can be very dramatic in appearance if the background is dark.

If the exact refractive index is known (and, to my knowledge, it is not for *Tridacna* and others), then the apparent color can be predicted. Constructive interference (assuming a refractive index of 1.42) would occur at wavelengths in the range of ultraviolet (355nm) through blue (468nm; Griffiths et al., 1992)*. In other words, the structural colors reflect ultraviolet light (which we cannot see) and those visible wavelengths of violet and blue (which is the color of many clams' mantles). Different refractive indices could lend any number of visible colors.

* Note: These researchers believed preparation of mantle samples may have caused some shrinkage, thus throwing a small monkey wrench into the works. When the calculation is 'corrected' for this potential error, the constructive interference range is extended into the green portion of the spectrum (and, as we know, violet, blue and greens are quite visible in mantles' reflected light).

DISCUSSION

If we have in mind a concept of what causes clam iridescence, then the next logical question is 'why?'

The most popular theory seems to be one of photoprotection, where potentially harmful ultraviolet (UV) radiation and Photosynthetically Active Radiation (PAR, especially in the violet/blue/green portions of the spectrum) are simply reflected away from the animal and its symbiotic algae.

A simple test, though certainly not conclusive, would be to compare clam coloration to depth. Theoretically, clams reflecting blue and green light would be found in shallow depths. See Table 1.

Table 1. Common clam coloration and depths. Casual observation suggests blue and green colors are common in clams from shallow water, while yellows and browns are often seen in specimens from deeper water. Is it really so?

Species	Common Depth	Common Colors
<i>Tridacna crocea</i>	to ~6m	Blue, Green
<i>Tridacna maxima</i>	Common to 7m, but to ~20m	Blue, Green, Violet
<i>Tridacna squamosa</i>	To 15-20m	Golden Brown
<i>Tridacna trevoroa</i>	20-33m	Brownish-Gray
<i>Tridacna gigas</i>	20m	Green-Brown
<i>Tridacna derasa</i>	4-10m, but to 25m	Golden Brown
<i>Hippopus hippopus</i>	to ~6m	Dull Greenish Brown

Before continuing, it should be noted that any attempt to associate fashion (coloration, in this case) with function is notoriously difficult. However, with that said, generally we see blue and green coloration associated with clams often found in shallow depths, with yellow-browns at deeper depths. However, there are major exceptions to this apparent trend where clams of a single species at the same depth display radically different coloration (see Fatherree, 2006 for some striking examples). *Hippopus* specimens also buck the trend.

So, other factors should be considered, such as genetic variability among specimens and possible effects of environmental factors. 'Types' (clades) of zooxanthellae found in photosynthetic clams should be studied when examining maximal depth ranges of clams.

GENETIC DIFFERENCES BETWEEN DIFFERENTLY COLORED *TRIDACNA GIGAS* AND EFFECTS OF LIGHT INTENSITY AND QUALITY ON *T. MAXIMA*

Burton (1997) used a laboratory procedure called electrophoresis in an attempt to link mantle 'coloration' and genetic variations. No clear relationship was established (although some interesting anomalies were observed in some of his colorful *T. gigas* specimens). This researcher believed unspecified environmental conditions (perhaps in conjunction with genetic predisposition) could cause 'expression of color'.

The most common environmental factor mentioned in hobby literature is that of light intensity or spectral quality. Alo (2005), in tests involving almost 400 *T. maxima* specimens distributed in 12 greenhouse systems and using different lighting setups in each system ('full greenhouse' light - peak PAR of 1,300-1,400mmol×m²×sec; 'shaded greenhouse' light - peak PAR of 700-1,000 mmol×m²×sec; and 10,000K metal halide light - maximum PAR of 1,450 mmol×m²×sec, decreasing to 280 mmol×m²×sec (!) after 13 weeks), found **only one** *T. maxima* to shift coloration (from green to yellow) during the experiment's progress (this specimen was held in a 'shaded greenhouse' tank). However, during the clams' light acclimation period (an initial 5-hour photoperiod increased by 30 minutes daily until a 12-hour photoperiod was obtained) **fourteen** clams changed from green to gold, and two switched from blue to gold.

Of interest to many hobbyists is one of Alo's observations - those clams maintained under the 10,000K metal halide lamps never expanded their mantles as fully as those exposed to natural sunlight of any intensity. His work suggests spectral quality was in play, and he attributes statistically significant high clam mortality to the UV-A spike at 365nm in the metal halide's spectrum (which is an interesting observation, since other researchers have suggested refractive/reflective qualities produced by iridophores protect mantle tissues/zooxanthellae from UV-A radiation. Since the metal halide lamps were suspended 20 cm (8 inches) above the water surface, is it possible that infrared radiation - heat - generated by the lamps was transferred to the clams resulting in stress?). For those wondering, Alo keep careful records of nutrients within his systems.

This researcher also includes some interesting work determining reflectance of clams' mantles using an Ocean Optics spectrometer and its software (See Figures 3, 4 and 5).

AND... A FINAL CLUE

If *Tridacna* clams' coloration plays a part in preventing zooxanthellae from getting too much light, we would see this as lack of photoinhibition in photosynthesis (or specifically, a linear increase of electron flow as light intensity increases - this determined by a PAM fluorometer).

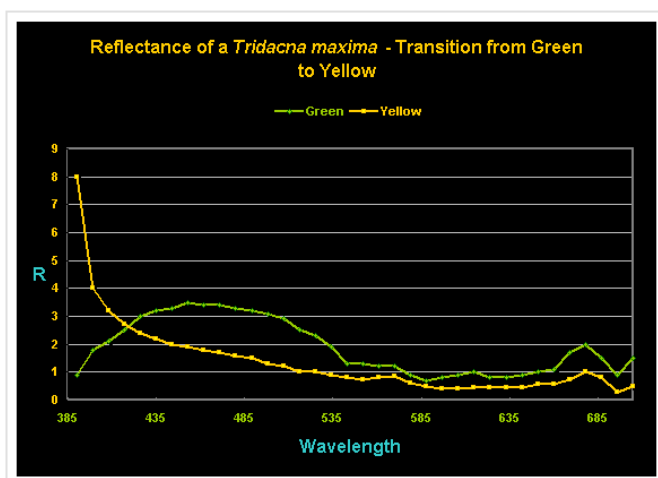


Figure 3. Reflectance of a single *T. maxima* specimen before and after its transition from 'green' to 'yellow'. (The 'R' legend on the y-axis stands for 'reflectance'.)

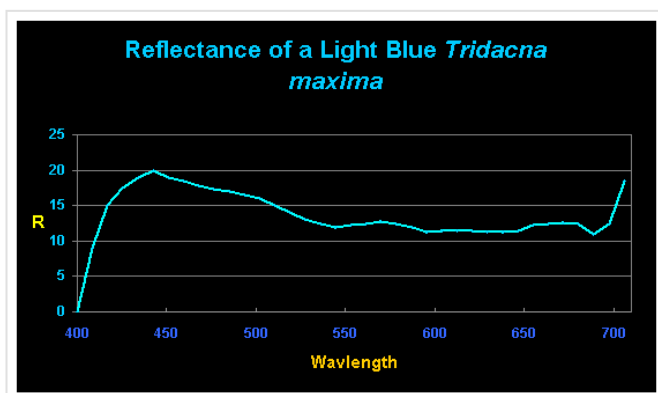


Figure 4. Reflectance of a 'light blue' *T. maxima*. Note the unusual and very strong reflectance at ~440nm - ~20% of the light falling upon the mantle is reflected. There is a muted spectral signature of zooxanthellae seen at 575nm and 650nm.

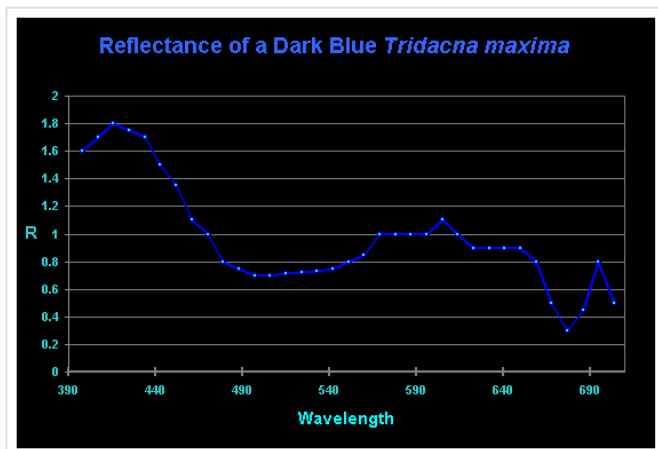


Figure 5. Reflectance of a 'dark blue' *T. maxima*. Compare this weak reflectance to that of the 'light blue' clam in Figure 4. Also interesting is the distinct 'crown' reflection at ~575nm, 600nm and 650nm- the typical spectral signature of zooxanthellae. Why do reflectances shown in Figures 3 and 4 lack this pronounced feature?

And this is exactly what we see (as shown in Figure 6). However, this is not proof that the mantle coloration is responsible - it could be due to self-shading of zooxanthellae within the relatively thick mantle, or some other factor.

This experiment was conducted while using an Iwasaki 400-watt 'daylight' metal halide as the illumination source. No photosaturation (much less dynamic photoinhibition) was noted at PAR values approaching 600 $\mu\text{mol}\cdot\text{m}^{-2}\cdot\text{sec}$, or ~30,000 lux. This does not mean the clam requires this amount of light; merely that it can tolerate it. *T. maxima* specimens can do just fine when maintained under much less light (200-300 $\mu\text{mol}\cdot\text{m}^{-2}\cdot\text{sec}$, or 10,000-15,000 lux, is generally sufficient).

ZOOXANTHELLAE CLADES FOUND IN GIANT CLAMS

As we near the closing of our discussion, we should examine the 'types' of zooxanthellae known to infect *Tridacna* clams. Reasons for including this information are two-fold. First, it establishes that clams of the same species can contain different zooxanthellae 'types' (clades). It also suggests that animals in the listings could possibly have the same light requirements.

As to the real question - Is there a genetic link between a particular clam recognizing a specific symbiont clade and a need for photoprotection via optical manipulations?

A3 - Found in a *Tridacna* clam (species unreported, Baille et al., 2000), *Tridacna crocea*, *T. maxima*, *T. derasa*, *T. gigas*, and another 'giant clam' (*Hippopus hippopus*; LaJeunesse, 2001). Clade A3 is tolerant of higher light levels (Hennige et al., 2006). Known hosts include the jellyfish *Cassiopeia mertensii* from Hawaii (LaJeunesse, 2001; LaJeunesse et al., 2004), *Montastrea faveolata* (Belize, across a depth range of 2 to 8m), a Belizean stony coral (*Siderastrea intersepta*, @ 8-15m; Warner et al., 2006), the anemone *Condylactis gigantea*, stony corals *Acropora palmata*, shallow-water *Acropora cervicornis*, and *Stephanocoenia michelini*. A3 zooxanthellae are known to produce 1 ultraviolet-absorbing compound - the MAA mycosporine-glycine (Banaszak et al., 2006).

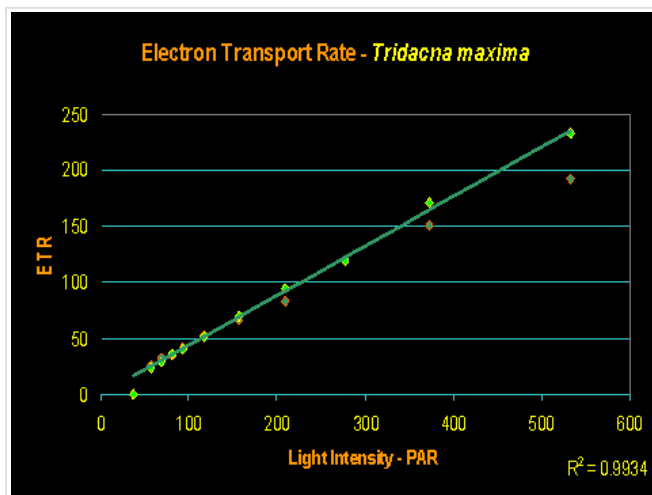


Figure 6. Rate of photosynthesis (Electron Transport Rate, or ETR) of a *Tridacna maxima* clam under an artificial light source.

C1 - Found in *Tridacna derasa* (1-8m); *T. gigas* (1-8m) and *T. maxima* (1-8m). Clade C1 is considered a 'generalist' zooxanthellae in that it infects a large number of photosynthetic hosts in the Pacific as well as the Atlantic, and is distributed over a wide variety of depths. Thus, corals and clams containing this clade could be considered highly adaptive in that they can tolerate high light but are probably best suited for lower light intensities. Clade C1 (along with C3, C21, C3d, C1c and C45) is believed to be an ancestral type from which other clades evolved (LaJeunesse, 2004). *Acropora cervicornis* (Baker et al., 1997), *Acropora divaricata*, *A. humilis*, *A. hyacinthus*, *A. longicyathus* (from the GBR; van Oppen et al., 2001), *Acropora palifera* (from Taiwan, Chen et al., 2005), *Acropora sarmentosa*, *A. tenuis* (GBR; Van Oppen et al., 2001), *Astreopora* (GBR, LaJeunesse et al., 2003), *Astreopora myriophthalma* (Taiwan; Chen et al., 2005), Caribbean anemones *Bartholomea* and *Condylactis* spp. (LaJeunesse et al., 2003), Great Barrier Reef 'corallimorpharia' and *Coscinaraea*, *Coscinaraea wellsii* and *Cycloseris vaughani* from Hawaii (LaJeunesse et al., 2004), *Cyphastrea* (LaJeunesse et al., 2003), *Cyphastrea chalcidicum* (van Oppen, 2005), Atlantic and Pacific *Discosoma* spp. (LaJeunesse, 2005), *Echinophyllia orpheensis*, *Echinophyllia lamellosa* (Chen, 2005), Caribbean *Eunicea* (LaJeunesse et al., 2003), *Euphyllia ancora*, *Euphyllia glabrescens* (Chen, 2005), *Favia* (LaJeunesse et al., 2003), *Favia fava* and *Favites abdita* from Taiwan (Chen, 2005), *Fungia* (LaJeunesse et al., 2003), *Fungia crassa* (van Oppen, 2005), *Galaxea*, *Goniastrea* (LaJeunesse et al., 2003), *Goniastrea rectiformis* (Chen, 2005), *Goniopora* (LaJeunesse et al., 2003), *Goniopora columba*, *Goniopora lobata* (Chen, 2005), *Herpolitha*, *Hydnophora* (LaJeunesse et al., 2003), *Hydnophora excessa* (Chen, 2005), *Icilogorgia*, *Lebruna*, *Leptastrea* (LaJeunesse et al., 2003), *Leptoria phrygia* (Chen, 2005), *Leptoseris incrustans* (LaJeunesse, 2004), *Linuche*, *Lobophytum*, *Merulina* (LaJeunesse et al., 2003), *Merulina ampliata* (Chen, 2005), *Merulina scrabacula* (van Oppen, 2005), *Millepora* sp. (LaJeunesse et al., 2003), *Montipora aequituberculata* (Chen, 2005), *Montipora cactus* from Indonesia (van Oppen, 2004), *Montipora cactus*, *Montipora curta* from Taiwan (Chen, 2005), *Montipora confusa* (van Oppen, 2004), *Montipora digitata*, *Montipora effluorescens*, *Montipora hispida*, *Montipora* sp., *Montipora spongodes*, *Montipora undata* from Taiwan (Chen, 2005), *Mycedium* (LaJeunesse et al., 2003), *Mycedium elephantotus* (Chen, 2005), *Pachyseris*, *Paulastrea*, Caribbean *Palythoa*, Hawaiian *Palythoa* (LaJeunesse et al., 2003), *Pavona desucata*, *Pavona frondifera*, *Pavona varians*, *Pavona venosa* (Chen, 2005), the 'bubble' coral *Plerogyra* (LaJeunesse et al., 2003), *Plesiastrea verispora* (Chen, 2005), gorgonians *Plexaura* and *Plumigorgia* (LaJeunesse et al., 2003), Taiwanese *Pocillopora damicornis* (Chen, 2005), *Polyphyllia*, *Porites* sp. (LaJeunesse et al., 2003), shallow-water *Porites cylindrica*, *Porites lutea*, *Porites solida* (from Taiwan; Chen, 2006), GBR *Psammocora* (LaJeunesse et al., 2003), *Pseudosiderastrea tayamai* (Chen, 2005), *Rhodactis*, *Rumphella*, *Sarcophyton*, Pacific *Scolymia*, *Siderastrea*, *Sinularia* (LaJeunesse et al., 2003), *Stylocoeniella guentheri* (Chen, 2005), *Stylophora* sp. (LaJeunesse et al., 2003), *Stylophora pistillata* (Chen, 2005), *Turbinaria* sp. (LaJeunesse et al., 2003), *Turbinaria mesenteria* (Chen, 2005), Pacific and Caribbean *Zoanthus* spp. (LaJeunesse et al., 2003).

CLAM COLORATION - IS IT CAMOUFLAGE?

Reflection of ultraviolet radiation could serve as a photoprotective measure to both host and symbiont, but is a poor idea for camouflage since many fishes can see well into the ultraviolet radiation range. Of course, the same applies to visible radiation. It

would seem that clam mantle coloration is just the opposite of the best camouflage strategy - that of invisibility, such as offered by transparency, where background light is transmitted through tissues. Further, the apparent self-protection reaction made possible by clams' photoreceptors (primitive 'eyes') to shadows is well known - the sudden closing of the valves, where water is forced out of internal cavities (usually enough to scare away predator fishes, such as *Thalassoma* wrasse spp. This, naturally, does not exclude camouflage's potential of predator avoidance, if you will. However, some researchers believe mantle coloration acting as camouflage to be a remote possibility).

There is also the possibility that physical qualities of the mantle could enhance photosynthesis. However, there is very little evidence supporting this hypothesis and it will not be discussed here.

I present this information for those truly interested in pursuit of answers. Unfortunately, I can no longer work on this since NELHA donated their *Tridacna* clams to the Waikiki Aquarium.

It should be apparent that we have a fairly good understanding of how clams' mantles are colorful, but a very poor one of why they appear this way.

This is an excellent project for a dedicated hobbyist to undertake. Quality spectrometers are becoming increasingly affordable as diffraction gratings find their way into different applications, and a fair number of instruments are now in hobbyists' hands. Those hobbyists willing to expend their time and money could be rewarded with unlocking mysteries of clam coloration - how they do it, why they do it - and perhaps turning those less-than-desirable specimens into 'killer clams'.

I will be glad to assist in any way possible. Contact me at RiddleLabs@aol.com.

MACNA! Atlanta 2008! www.masna.org

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ADVANCED AQUARIST'S ONLINE MAGAZINE
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REEFKEEPING EVENTS

WHAT'S HAPPENING IN YOUR AREA?

By Advanced Aquarist Readers

Check to see if an event is happening in your area!

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Link to original article: <http://www.advancedaquarist.com/2008/1/events>

DO YOU HAVE AN UPCOMING EVENT?

If so, please email us at feedback@advancedaquarist.com and let us know about it!

2008 SOUTHWESTERN CORAL FARMERS MARKET THIRD ANNUAL EVENT

Date: Sunday, February 24th, 2008

Time: 10:30 AM to 4 PM

Location: Hilton Ontario Airport Hotel, 700 North Haven Avenue, Ontario, California 91764

Website: <http://www.sw-cfm.com/>

This 2008 Coral Farmers Market sanctioned event is the third annual event run by the SouthWestern Coral Farmers Market company. We now have confirmed reservations for 35 coral farming and exhibiting vendors who will be selling or displaying their captive grown, cultured corals or reef related products to the public. This is scheduled to be the largest Coral Farmers Market event to date. This will also be one of the largest displays of the absolute best exotic captive grown corals ever presented to the buying public. We expect at least 400 total attendees.

Some of the best coral farming vendors from Southern California, the states of Utah, Nevada and Arizona along with farmers from the California Bay Area and Sacramento will be setting up coral displays. Farmers include aquarists, retail reef shops, online coral shops and full scale coral farming enterprises. There will also be exhibitors present who will be demonstrating and selling their products. This SW-CFM event will also feature coral auctions, raffles and door prizes throughout the day. Reef aquarists new to the captive reef market can also expect to see a fine collection of easy to keep beginner corals. For the first time in a Coral Farmers Market event we will also have a Marine Fish Hatchery company exhibiting and selling captive bred marine fish. Aquarists and enthusiasts can attend this one-day event by purchasing a SouthWestern Coral Farmers Market day ticket online for (\$15) up to 4 weeks prior to the event. Within 4 weeks of the event the online ticket prices will be (\$25). Tickets will also be sold at the door (\$30) during the day of the event, but may be limited by occupancy restrictions. We are also encouraging our farmers to bring plenty of farmed soft corals along with their usual excellent farmed stony corals.

THE 24TH ANNUAL RALEIGH AQUARIUM SOCIETY WORKSHOP AND AUCTION

Dates: Friday, February 29th - Sunday, March 2, 2008

Location: NC State Centennial Campus, Engineering Building 1, 911 Partner's Way, Raleigh, NC 27606

Website: <http://raleighaquariumsociety.org/main.html>

Please note that this is a different location from years past. Here is the schedule:

Friday: The native fish collecting trip will be during the day and our Marine Aquarium presentations will be that night. So far we know we have Brian Plankis of Project DIBS speaking and we are in the process of confirming our second speaker. There will also likely be a frag swap and fragging demonstrations that night. More details will follow.

Saturday: Saturday will include several freshwater fish and plant presentations as well as some general presentations which pertain to both freshwater and marine aquaria. More details will follow.

Sunday: This is our annual auction of fish, plants, corals, inverts, dry goods, tanks, and anything else aquarium related. Anyone is welcome to buy or sell. A portion of all proceeds go to benefit The Raleigh Aquarium Society and costs related to the workshop.

More details will follow. If anyone has any questions about the Workshop, please feel free to e-mail carmiejo@hotmail.com or Ltwaddle@yahoo.com.

CTARS MARINE AQUARIUM CONFERENCE

Date: April 13, 2008

Time: 9 AM - 5 PM

Location: Courtyard Marriott, 4 Sebethe Rd., Cromwell, CT

Website: <http://www.ctars.org/default.aspx?uc=conference>

Featuring:

- Adam Blundell
- Mystic Aquarium
- Joe Burger

- James Fartherree
- Huge Raffle
- Club Frag Swap
- Vendors

No tickets will be sold at the door.

MIDWEST FRAG FEST

Date: May 3-4, 2008

Time: Saturday (9 AM - 5 PM), Banquette @ 6 PM; Sunday (9 AM - 2 PM), raffle 3 PM

Location: Clock Tower Resort and Conference Center, 7801 E State Street, Rockford, IL 61108-2721, US

Website: <http://midwestfragfest.com/index.html>

Midwest Frag Fest is the premier coral conference across the midwest. Frag Fest 2008 will be held on May 3rd and 4th at the Clock Tower Resort and Conference Center located just off of I-90 in Rockford IL. Our goal is not only to provide both hobbyists and vendors across the region with the best experience at an event of this type, but to donate a portion of the proceeds towards reef conservation and also give back to the community. Admission will be discounted with the donation of canned goods for a local food pantry.

Attendee information:

- Hotel accommodations are available at a reduced rate at the Clock Tower Resort for only \$94 per night.
- Full event pass includes admission to all speakers, trade show and frag area, banquet dinner, and event T-shirt. The cost is \$55. Sign up fast. First 40 to register will sit at a speakers table at the banquet. What a wonderful opportunity to chat with the pros
- One day pass with all access for that days events are available as follows:
 - Saturday with dinner \$45
 - Saturday with out dinner \$20
 - Sunday \$20
 - Trade show, fragging area only \$10
 - All at the door admissions reduced by \$1 per can good donated up to \$5 off

Speakers include Adam Blundell, Rod Buehler, James Fatherree, Mike Paletta, Gary Parr, Steven Pro, and Randy Reed

MARINE AQUARIUM EXPO, SATURDAY, APRIL 5 AND 6, 2008

The First Annual Marine Aquarium Expo (MAX) is a TWO DAY EVENT at the Orange County Fair & Exposition Center (Costa Mesa, CA) April 5-6 2008!

Dates and Times:

- Saturday, April 5th 12:00 noon to 8:00 PM
- Sunday, April 6th 10:00 AM to 6:00 PM
- [Calendar Information](#)

Event Information:

- Over 100 exhibitor's booths!
- Manufacturers, Wholesalers, Retailers, Exhibitors
- Livegoods/Drygoods for sale throughout the building
- 8 major Speakers lined up! (4 per day)
- Multiple Workshops and Demonstrations
- Children's Petting Pool and education area (pending)
- Frags! Frags! and more Frags! need I say more?

Admission: Adults \$10.00, Seniors \$5.00, Children 12 & under are Free!

MAX is held in Building #12, (22,000 sq. ft. fully-enclosed, air-conditioned exhibit hall). An adjoining 7,000 sq ft. covered courtyard will host much of the peripheral activities (speakers, workshops, raffles, seating area, etc.). This greatly enhances the space available inside building 12 for commerce. In other words: More room for everyone!

HUGE RAFFLE at the end of each day! Special Note: 50% of ALL Raffle Proceeds will go to 10 select public charities, all of whom are participating in MAX either directly or indirectly. (some represented by hobbyists doing a workshop on behalf of the charity)

This is a VERY family-oriented event, so please plan on bringing the entire family for a weekend of spectacular exhibits, speakers, workshops, displays, and other entertainment. Great food, clean restrooms, even a seating area.

Ladies and Gentlemen, this event is expected to attract over 3,000 hobbyist from all over the United States! Participating vendors and attendees alike are coming from all parts of the country. In fact, MAX is soon to become the largest event of its kind in the entire North American continent in terms of overall attendance. You don't want to miss this one!

For more information, visit us at: <http://www.marineaquariumexpo.com>

Contact Information:

Kevin T. Adams, MBA, Promoter
 "Marine Aquarium Expo 2008"
 8072 Central Avenue
 Garden Grove, CA 92844
info@MarineAquariumExpo.com
 (714) 530-1094 office
 (714) 260-6660 cell

(please note: MAX is not affiliated with any club organization)

INTERNATIONAL MARINE AQUARIUM CONFERENCE '08, MAY 30-JUNE 1, 2008

Just Imagine...a weekend where you can see live presentations by the most widely known, well-respected authors and lecturers in the marine aquarium hobby.

At the [International Marine Aquarium Conference](#) the speakers will be covering all the latest information and research on marine aquarium fish, corals and invertebrates. Meet with them socially, see exhibits by some of the foremost manufacturers and dealers in the aquarium hobby, and get some great deals on conference specials.

IMAC is open to ALL hobbyists. You do not have to belong to a marine aquarium society or even own a reef tank to attend, just be interested in learning more about this fascinating hobby. IMAC is a non-profit venture by hobbyists for hobbyists to insure the continuation of an annual educational event for aquarists, at a reasonable cost.

Whether you are a seasoned aquarist or just a beginner, IMAC is something you need to take in. And IMAC is put on each year by the same people, so if you attended IMAC in 2003, 2004, 2005, 2006 or 2007 you know the high quality of the show that we will put on.

IMAC 2008 will take place in Chicago, Illinois, USA - May 30, 31 and June 1 at the Crowne Plaza Hotel, Chicago IL:

Crowne Plaza Hotel, Chicago O'Hare
 5440 North River Road
 Rosemont, IL 60018, USA

For more information, visit <http://theimac.org/> or contact [Dennis Gallagher](#).

MACNA XX, SEPTEMBER 5-7, 2008

Presented by [Atlanta Reef Club](#) and [MASNA](#), MACNA is the largest hobbyist marine conference in North America. New aquarium products, vendors will often wait until MACNA to release new products into the hobby. Hobby professionals, you will have a chance to meet and mingle with professionals in the hobby like Eric Borneman and Anthony Calfo. A chance to be at a conference with hundreds of other people just as obsessed with aquariums as you are.

We have selected the Westin Peachtree Plaza as the host hotel for this event. It is the tallest hotel in the western hemisphere. Our negotiated room rate is \$119.00 per night with discounted parking. Everyone that stays in the hotel will be given free internet access from their rooms.

This 73-story tower, topped by the revolving Sun Dial Restaurant, Bar & View, graces the heart of Atlanta. Connected to AmericasMart, The Westin Peachtree Plaza, is steps from CNN, Georgia Aquarium, Georgia World Congress Center and the Georgia Dome.

Contact Information:

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AQUARIUM FISH

LARGE ANGELS IN THE HOME AQUARIUM, PART 1

By Jim McDavid

The information in this article is by large the result of my 22+ years of experience observing these animals in my own tanks, as well as tracking the results obtained by other hobbyists during that time.

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Link to original article: <http://www.advancedaquarist.com/2008/1/fish>

Thinking of purchasing an Angelfish? Then this article is just for you. Similarly, if you've attempted to keep one of these magnificent animals in the past only to encounter problems, then the next few pages should help tremendously. Of all the fish that can be found on a tropical coral reef, there is nothing more majestic than angelfish. Indeed, if my experience over the past few decades dealing with and helping people in this hobby is any indication, this group of fish is near the top of the list in popularity. Although definitely not for everyone, this doesn't stop just about every marine aquarist from lusting after and trying their hand at keeping one of these beauties in his or her living room at some point or another in his/her fish keeping careers. The results as with any species can run the gamut, but there are concerns with these genera that I think warrant a detailed look.

The information in this article is by large the result of my 22+ years of experience observing these animals in my own tanks, as well as tracking the results obtained by other hobbyists during that time. I've had plenty of time to learn what does and does not work, both under my care and that of others. Success with these fish cannot be measured in months, or a few years. These fish can live for over 20 years in captivity; therefore only long-term results are salient when discussing what is best for their well-being. For the most part, this article is not the result of research, but hard earned empirical knowledge.

ON WITH IT THEN!

Just like the freshwater ones right?

Not exactly, in fact not even close. Freshwater angelfish belong to a group of secondary division freshwater fish (close lineage to marine fish) known as the cichlids, which also contain popular aquarium fish such as the Oscar and Firemouth. While both the marine and freshwater angels belong to the order perciformes, and share a vague, tall bodied, laterally compressed similarity, the practical resemblance ends there.

Marine angels can be the length of your little finger or as large as 24 inches. They can be muted, garish, or anything in between. They are intelligent, and like the groupers and triggers that I've written about previously, they have loads of charisma and personality. The large angels that we will be discussing here are also rather robust as adults, despite a somewhat delicate, often butterfly-like nature when young.

WHAT DO I NEED TO KNOW?

Plenty! This article will be in 2 parts, and a little long-winded compared to the previous two on hinds and triggers, simply because



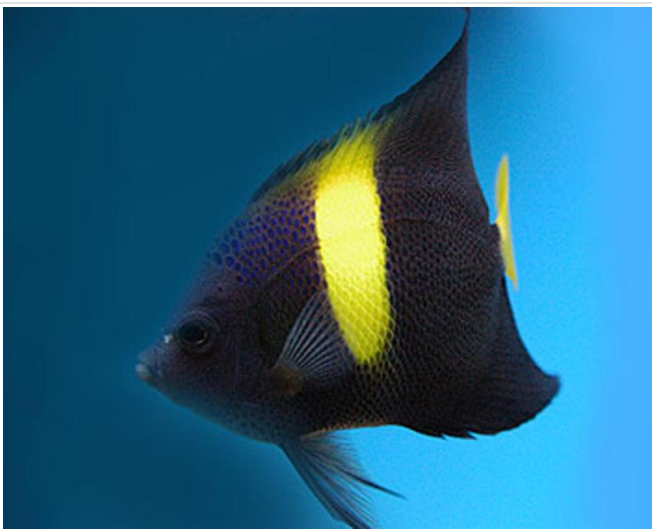
A resplendent *Pomacanthus imperator* adult. Photo by Teresa Zuberbühler, <http://www.starfish.ch/>.



Pomacanthus imperator in its juvenile colors. Photo by Teresa Zuberbühler, <http://www.starfish.ch/>.

there is much more than needs to be said. When considering purchasing one of these fish, you have to know your stuff, and you have to be prepared! These animals are by most measures one of the less forgiving families available to the marine fish keeper, and this unforgiving nature manifests itself in a variety of ways, including space requirements, nutritional requirements, temperamental considerations, and usually a combination of the three. This of course varies drastically with genus and species. There is too much variation and too many idiosyncrasies within this family to impart all necessary information here, so this article will not, and cannot be the extent of your research. However, I'll attempt to give an overview of the family, and the must do's and don'ts in order to help you keep these fish successfully. With regards to specific species, I'm going to speak in terms of what the hobbyist is likely to encounter with regard to hardness and temperament for that species. Nothing is all the time, and you may have a stroke of luck with normally fragile species, or have a string of bad luck with a species that is generally trouble free.

The most important thing to keep in mind with regard to marine angels is that they do not suffer a lazy keeper easily - they are for advanced keepers with the resources to give them what they require to thrive. In the grand scheme of things, when compared to many other fish species that are available, they are decidedly on the delicate side. This tendency is understated not only in most articles and books in my opinion, but by many keepers as well. This I believe is because many mistake a living fish, with a thriving fish in resplendent health. They see a fish swimming around still after a year, or 4 years, and assume all is well. Often in fact this apparently healthy fish is heading towards doom, even though it may not show outward symptoms of disease or stress. Below I will examine further why this is, and how to mitigate the potential problems. For now it's enough to say that the keeper who neglects his initial research, fails to quarantine his new arrival, fails to give his charge the proper nutrition, the proper space, or fails to perform adequate maintenance on the tank itself is asking for problems. So, let's get down to business and figure this family out!



Pomacanthus asfur - juvenile.

DO I HAVE THE SPACE?

As the title of this article indicates, by home aquarium standards these are large fish. This is a subjective term of course, and adult size varies from 6" to 20" or so in the wild depending on species. While adult size in the wild doesn't necessarily translate into size attained in the home aquarium under average conditions (more on this below) you can easily choose a species that will be very at home in your 80 gallon, or very, VERY cramped in a 200 gallon tank if you're not careful. So the first thing you need to determine is what species your tank will accommodate in the real estate department. Given the diversity of the family, and the varying growth rates and sizes of various species, coupled with conditions that vary greatly from one living room to the next, generalizations are difficult at best here. To further complicate this matter, some angels will attain a size close to their wild adult maximum under the right conditions, while others almost never reach full size in most living room tanks, even relatively large ones. As a general rule, and I stress that this is a generalization, most larger species can be expected to eventually attain half to three quarters of their maximum wild adult size under very favorable conditions. Most of the time, growth also slows as size increases, and appears to all but stop at various sizes depending on species and conditions at hand. This is due to stunting, and is a problem not dealt with in most publications with regards to this family.

The fact that minimum tank size is often grossly understated for most species in some trusted sources doesn't help matters either. I will stress the previous point by saying that some very popular, current and often-referenced material is preposterously off the mark with regard to tank requirements for these fish, including just about every reference you'll find on fish retailer websites. In short, the tank sizes given insure a stressed and possibly stunted animal, and therefore the accompanying health issues and shorter life span that comes along with it. A German Shepard will live in a 10' by 10' room for years, and he might look just fine for the most part during that time, but would you subject the animal to this? I'm betting you wouldn't. The conditions many keepers subject their fish to, often from the guidance of local fish stores, books, or fellow keepers posting in online forums is tantamount to exactly this.

What happens when you keep an angel in a tank that is too small? In short, you induce psychological and physical stress that has profound effects on the growth, color, immune response, and life span of the fish. In a physiological sense, cramped surroundings encourages stunting, which in extreme cases affects muscle and organ development, and leads to a dead fish well before it's lifespan is reached. Minimally, a tank that is too small prohibits these fish from reaching their full majesty not only with regard to size, but some species will not attain full adult coloration, or the adult colors will be lackluster compared to wild specimens. (Diet plays into this too, more on that later).

It's unfortunate that many aquarists do not appreciate the psychological stress that cramped surroundings create. Some species adapt to a confined environment with no apparent ill effects, at least not in the first years of life. Angels do not fall into this category however. Aside from the buildup of growth limiting substances that cramped surroundings encourage, psychological stress stunts growth in a huge way as well. More importantly in

the short term - it breaks down the immune response, which will invariably lead to disease. While often we see disease almost immediately due to this stress, these effects are not always apparent at first, and make take weeks, months or even years to become evident, again depending on species and circumstances. A tank might be too small because of the size, or eventual size of the angel, or it might be too small because of tank mates that you've chosen to keep with your angel. Forcing an angel to co-habitate with aggressive species, especially without allowing enough room for the angel to escape the aggressor's attentions is a recipe for trouble. In any case, the results will be the same for the angelfish eventually. Further, what would be an acceptable sized tank for a 10" trigger is not necessarily an acceptably sized tank for a 10" angelfish. This is simply because the Pomacanthids are generally more prone to the psychological stress that comes with going from the infinite ocean to the confines of a glass box. Remember, an angelfish in the wild often maintains a territory as large as the lot that your house is sitting on! In short, they need more physical space than you're probably used to providing, and certainly more than most wishful thinking in current literature indicates.

So what does all of this mean in actual practice? While some of the *Chaetodontoplus* species will live long term in quarters as small as 80 gallons, most *Holocanthus* and *Pomacanthus* species require at least a 250 to 300 gallon tank to live a proper life span in optimum health. If this sounds ridiculous, think of the size difference between a tennis court and an 8' aquarium. I think asking the fish to adapt to the 300 gallon tank is quit enough, don't you?

Let's look at a popular, easily obtained species - the Koran Angelfish, *Pomacanthus semicirculatus*. This species attains a maximum adult size of 15" or so in the wild. Now, most literature will tell you that you need anywhere from a 100 to 135 gallon tank as a minimum to maintain this species. Not so fellow fish keepers! Will a juvenile Koran live in a 135-gallon tank for quite some time? He sure will. Will he live for 20 years, reach his full adult size and thrive? Most definitely not - he'll most likely become stunted and eventually, sick. A more appropriate long term home for this species would be in the 200-gallon range, or even better, 300 gallons. Having said this, this is one of the species that will suffer least from such treatment. Other species that are often lumped

into the "minimum 135 gallon tank" category will suffer to a greater extent, both in ways that are, and are not readily apparent, and often simply wither and die for reasons typically unbeknownst to the keeper. To see the Emperor or Queen angel sited as needing such meager quarters is just ridiculous. An adult Queen angel, by the time fin trailers are measured pushes 2 feet, a 135-gallon tank is typically 18" wide! The Annularis Angel pushes a foot in length, yet many would have you house it in a 100 or 120 gallon. The Emperor Angel attains almost 18" - again, the idea of a 135-gallon tank is just silly.

The justification that the fish will not attain adult size in captivity, and therefore not require such a large tank is erroneous and indicative of poor husbandry philosophy. The health of the fish kept under such methodology will suffer sooner or later. There are fish that do not suffer as greatly from such an approach (within reason) such as the triggerfish, or many grouper species. While a genus or species being generally forgiving in this regard should not be interpreted as license to cram them into tight quarters, the Pomacanthids offer no such level of forgiveness. They eventually and invariably show faded color, and/or withering health, and begin a long, (or not so long) downward spiral. If that all sounds discouraging, no worries, the good news is that you can split the difference between a small inland sea in your living room, and a tank that is too small to allow for a long and healthy life for your angelfish. The bottom line here is that you will have greater success the more room you provide from the get-go, even beyond the sizes I'm about to list. This means that despite it's small size, a 3" juvenile Queen angel will do much better in the long run starting out in a 180 gallon tank than it will an 80 gallon tank, even though from a space perspective, 80 gallons would seem large enough for the time being, and certainly would be for a 3" Hawkfish. Remember, we're concerned just as much about the psychological effect of the environment at this point, and by extension we are managing the stress level, immune response, growth rate and color of our specimen. When upgrading to something larger, do so before he's starting to look too small for the 180 gallon, say around 6" or so. To reiterate, artificially stunting these fish by keeping them in inadequate quarters is not appropriate husbandry practice, despite how common this practice is, whether it be from ignorance, or lack of space, or limited finances. While the above statement moves a majority of



A juvenile French Angel, *P. paru*.



Pomacanthus semicirculatus - adult. Photo by Teresa Zuberbühler, <http://www.starfish.ch/>.

aquarists out of the realm of being able to keep these fish, considering the frequency with which these fish die under the care of well meaning but ill-equipped hobbyists - I think this is justified. This family is without a doubt for advanced keepers in multiple respects. Just because a fish is collected and imported, does not mean it's appropriate for your living room. The aquarist must be, above all things, conscious of the well being of the animals he/she keeps.

As stated before, these fish generally do not grow quickly, even under the best of circumstances, but some species will buck this slow growth tendency, even in less than adequate surroundings, such as *Pomacanthus paru*, the French Angelfish. This species will not only grow large, it will do it rather quickly, often going from the size of a half dollar to the size of a dinner plate in a year. While I haven't personally seen any other species grow quite this quickly, that doesn't mean it's not possible. By large though, fish belonging to this family are relatively slow growers in captivity when provided with typical accommodations, and for the most part they will not reach full adult size in tanks that are available or affordable to most hobbyists.

HOW DO I SELECT A HEALTHY SPECIMEN?

As with any marine fish, selecting your specimen is where your success or failure in keeping the animal begins. This is easier said than done of course, as the fish has been through quite an ordeal by the time it reaches your local retailer. All things being equal, the general effect of this ordeal varies from one genus or species to another. As mentioned above, the Pomacanthids are among the most sensitive species of fish to stress. The rigors associated with capture (often with cyanide), being held with little or no food, then being shipped halfway around the world in a bag is taxing to even the most robust species.

So, what do you look for? In short, a flawless, alert looking specimen. This means no sunken regions on the body, either on the dorsal or ventral regions. Fins should be intact, with no light or discolored patches on the eyes, fins or body. There should be no sores, pits or lesions of any kind along the lateral line, or anywhere on the fish. Angels often turn sideways to maneuver through holes or crevices in rocks or coral - aside from this exception, the fish should be swimming upright at all times. The specimen should show awareness of your presence, even if this means it insists on hiding behind something to avoid you, which is quite common with some species. The fish should of course show good color!

As with many species, you should also avoid specimens that are too small. Anything under 1.5" is not likely to be sturdy enough, or eat enough to enable it's survival beyond a week or two. Likewise, avoid larger specimens above 6" or so, as they are unlikely to adapt to captive foods and conditions. Always ask to see the little guy eat, but be aware that many specimens will be much too stressed to take any food in the store's holding tanks. Still, if given the choice between two identical, healthy fish, take the one that eats - it will ease the acclimation process when you finally get him home.

ONE MORE THING... LOCATION, LOCATION, LOCATION!

Specifically, the location that your angel fish to be was collected from. Unfortunately, the use of Cyanide to collect marine fish is still prevalent in many regions. Fish that are stunned, or "juiced" with cyanide during collection, and survive the initial exposure (many die outright) have been shown to have an extremely high mortality rate 55.9% to 61% 40 days post-importation. (Jay Hemdal pers comm.) Worse, the fish often appears normal, even spectacular when viewed at the fish store and may even eat well, only to "crash" a few weeks, or even months later for *apparently* no reason. I have seen at least 2 authors call into question the validity of studies attempting to prove the long-term effects of cyanide on marine fishes, and I commend any effort to add to our knowledge base. However at the same time they do acknowledge that concentrated exposure to cyanide is most definitely deadly to marine organisms, and there are other more recent studies that validate delayed mortality after cyanide exposure. Even if the specific long-term physiological effects of cyanide are still unclear on fish that initially survive exposure, it's clear that cyanide is a poison, and in high concentrations it kills fish outright. In my opinion, the need to debate the issue ends there. When dealing with toxins, there are very few examples of "X-amount kills instantly, but Y amount has no ill effect". It's the belief of this author based on 22 years of observation at all levels of the hobby, that at least some seemingly inexplicable deaths post-capture are caused by cyanide poisoning. My advice is to let others poke holes in published graphs and charts, and do your best to stay away from cyanide caught fish - period. At the very least, the additional physiological stress and negative health effects that this method most likely brings on are not something our angel friends suffer easily. My own empirical data on Pomocanthids caught in regions such as the Philippines where cyanide fishing is rampant supports this contention.

Where does this leave you? For starters, from time to time captive reared angels are available from online dealers. These are usually captured larvae that are reared in pens or tanks, and are most suitable for the aquarium. At the time of this writing, I've been unable to verify the legitimacy of the current captive reared offerings out there, so proceed with caution. Investigate thoroughly before purchasing! Lastly, and most importantly, you can arm yourself with research as to where cyanide fishing takes place, which locations are cyanide free, and where your



The Queen Angel, Holocanthus ciliaris.

prospective new aquarium inhabitant hails from. This way not only can you be sure for instance to avoid an Emperor angel that was collected in the Philippines, if the store employee tells you he's from Mexico, you know you're not getting accurate info, and to steer clear of that fish. Any reputable dealer will know where his fish come from!

A good place for information on locality for just about any fish species is www.wetwebmedia.com and a bit more technical, www.fishbase.org. Up to date information regarding where cyanide fishing is taking place, and what areas are safe is a bit harder to come by. The following is a list of localities that are known more or less safe from cyanide use.

The Red Sea, Australia, the Cook Islands, Sri Lanka, East Africa and Fiji (Jay Hemdal pers comm.), as well as Papua New Guinea, Mexico and Tonga, (Gresham Hendee, pers comm.)

This is not necessarily a complete list, nor am I contending that every fish from everywhere else is doomed to die from cyanide poisoning. I've purchased plenty of fish from "unsafe" zones and did just fine with them. The point is that you need the variables on your side, and ending up with a "juiced" fish is a good one to eliminate, especially with this family. Cyanide fishing is the most rampant now in Indonesia/Bali, with the Philippines coming in a close second. (Steve Robinson, pers comm.)

One final note on cyanide, and that is the damage this practice causes not only to the environment, but also to the indigenous peoples in the regions where this practice occurs. Most fishermen are not tropical fish catchers, yet they all lose when habitat is destroyed by cyanide fishing - resulting in poverty and genuine suffering for these populations. (Steve Robinson, pers comm.) As aquarists, we are the least of the victims. For these reasons alone we should strive to avoid purchasing fish collected with this toxin.

Next issue, we'll look at further husbandry requirements, including acclimation, compatibility and stocking methods, as well as diet and species profiles.



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LATERAL LINES

WATER FLOW PART 1: WHERE TO BEGIN

By Adam Blundell M.S.

How can a hobbyist decide how to set up their tank if they don't have an idea on how the water will move in the tank?

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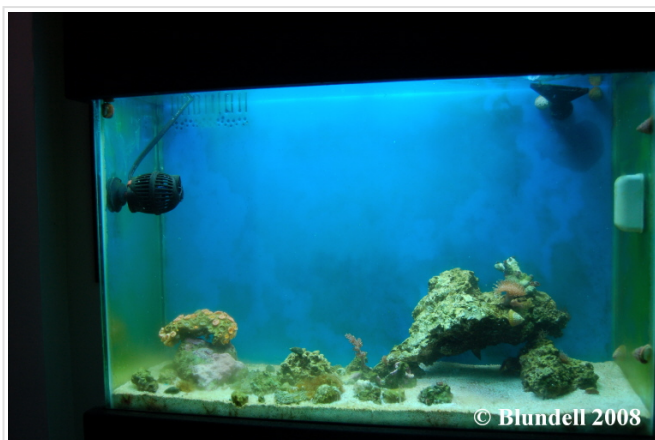
Hello and welcome to the Water Flow series. This series of articles will be my best attempt to take real world scientific information, and put that into helpful hobbyists terms. That isn't to say that the scientific information isn't hobbyist friendly, only to say that I receive emails and suggestions for topics that often address water flow issues.

My final "goal" for this series to answer some basic questions. I get emails all the frickin' time asking me questions like "what kind of pumps should I use", "are brand X pumps worth the money", "what is the best kind of flow", "what is this random flow and linear flow I keep hearing about"....

I'm at a loss for words. How can tell someone what pump to buy when I don't know a thing about their desires? More importantly how can a hobbyist decide how to set up their tank if they don't have an idea on how the water will move in the tank?

SETTING UP A SALT WATER AQUARIUM

Before you ever put water in your aquarium make sure you know how you are going to move that water around! You wouldn't believe how many people (most likely including you, the reader) set up their aquariums and then start to think about how the water is going to move around. Well, for your next aquarium (lets face it everyone sets up another) lets try to tackle this issue before hand.



Invertebrate nano tank.

Is it a reef tank? Do you have a sump? How will the water produce gas exchange? How will the water carry nutrients to the filtration system? Is this a biotope? Is this a planted aquarium? WHAT TYPE OF FLOW DO YOU WANT?

DEFINING THE TERMINOLOGY

I love semantics. I'm not sure why but terminology in general is just fun. Maybe it is the challenge of working with something that is almost always wrong. Regardless of the reason, I do think it is important for hobbyists to first grasp these terms and know how they relate to their aquarium.

RANDOM FLOW

I hear this term about 10 times per day. Let me be clear, you do NOT want truly random flow in your aquarium. Example- you take 10 powerheads and stick them in your 75 gallon tank, just hanging their by the cords. You turn them all on and let them blow around. This means, that just by random chance, everyone once in a blue moon, completely random, all those powerheads for a moment will be near the surface facing straight up blowing water out of the tank and all over the lights. It also means that every once in a while the powerheads will blow directly into the sand all together at one time. It also means that all the powerheads would face directly onto your frogspawn and blow all the tissue right off. Hey, if it is random it is bound to happen at some point.



Whether you plan to set up a small invertebrate tank or a seven hundred gallon aquarium, you will need to think about water movement and flow design.

The key to defining Random Flow is that by definition it is NOT predictable.

CHAOTIC FLOW

This is what people describe when they usually say Random Flow. Chaotic Flow means that the moving water will make contact with water moving in a different direction. Example- you take two powerheads on opposite sides of the aquarium and you face them both towards the middle. At the middle of the aquarium the two bodies of fluid run into each other and the momentum is dissipated by pushing water in different directions. This is certainly NOT random. In fact it is very predictable. If you see an aquarium like this and look at how the water is moving, you can predict how the water will be moving 5 minutes later, 10 hours later, and even 2 weeks later. It will be moving just like it is right then and there in front of you.

ALTERNATING FLOW

This flow is characterized by changing the direction, speed, volume, or some other aspect of the water flow. Example- the most common example I can think of is the rotating output devices like a Sea Swirl. If you aren't familiar with them I'll just simply state that they basically take water from a powerhead and push it through an outlet. However, unlike a standard powerhead the Sea Swirl sweeps that outlet horizontally back and forth changing the direction that the water is coming out. Now, let's say you have a few of these in your tank. They continually move back and forth and change where the water is going. This creates some Chaotic Flow, but that Chaotic Flow is changing... in fact that is why it is Alternating Flow. This is once again NOT Random Flow. I can look at an aquarium with several Sea Swirls. I can time how long it takes each of them to move back and forth. Then, I can calculate where they will be pointing in 10 minutes, in 10 hours, in 10 weeks. This is certainly NOT random but is in fact very predictable.

LAMINAR FLOW

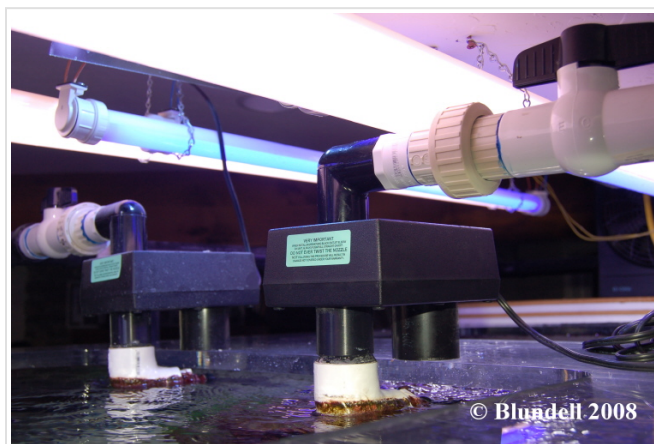
Water flowing in one direction is termed laminar flow. It also describes the idea of bulk water flow in that direction. Example- having all the water in your tank moving from the left side to the right side. This could be done by pumping in a lot of water on the left side, and having an overflow on the right side where the water leaves the tank. Thus all the water is slowly moving from left

to right. Until recently this wasn't used, but some adventurous hobbyists have really had fun with this. Another Example- having all the water flow around the aquarium in a circular motion. To get this idea imagine sticking your arm in a 5 gallon bucket and swirling the water around in a circle. If you did that in an aquarium the water would always be flowing in one direction in relation to any fixed item (like a coral).

The aquarium shown here uses two closed loop systems. The inlets for each closed loop are on the opposite sides of the aquarium from the outlets. Therefore as one closed loop is running it drains water from one side of the tank and pumps it into the other. All the water is flowing in one direction (let's say from left to right). Then 4 hours later that closed loop turns off and a second closed loop turns on. This is plumbed in the opposite direction so now all the water moves from right to left for the next 4 hours. This is Alternating Laminar Flow... pretty cool!

SLOSHING FLOW / TIDAL FLOW

This type of flow has been nearly non-existent in the hobby until recently. This type of flow is characterized by pushing a very large volume (maybe the entire tank volume) in one direction for a short time (let's say 2 seconds) and then pushing it all back in the other direction. This is usually very predictable. Example- Having the entire aquarium sitting on a Teeter-Totter (seesaw) so one side moves up, and then down, and then up, and then down (as



This SeaSwirl is a device which rotates the output of a pump. This causes an alternating flow pattern.



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the other side moves opposite). Another Example- having a piston on the side of the aquarium pushing in, then pulling out, then pushing in, then pulling out. Either way would cause all the water to move back and forth.

SURGE FLOW

This is characterized by moving the bulk of the water up and then down, then up, and then down. Example- dropping a five gallon bucket of water into your 75 gallon aquarium all at one time, then pulling back out an entire 5 gallon bucket. This is seen in tide



pools as a wave crashes in and the water all "surges" up filling the pools, then drains back out. This happens over and over with each passing wave. It also takes place on reefs where strong currents and strong winds cause large waves. A scuba diver may notice this as they are literally picked up, then set down, then picked up, then set down by the force of the water around them. As a side note, it is a blast to witness this under water. Nothing is cooler than seeing a whole school of yellow tangs swimming by as they get lifted 4 feet up into the water column, and then are pushed back down with each passing wave. Note: this is actually done in a circular motion.

STAGNANT FLOW

This is really the lack of water flow. Most aquarists are trying to avoid this, but some aquariums are actually designed to minimize water flow. Delicate animals (say jellyfish) or coldwater systems are often made to prevent water flow.

CIRCULAR FLOW

Describes the vertical movement of water in a circular pattern (remember horizontal circular flow is a type of laminar flow). Example- most kreisel tanks are designed to keep items slowly moving in a circle. This is often done to produce a "suspended" environment. The most common examples include jellyfish aquariums and larval rearing aquariums.

CONCLUSION

Water flow is a huge topic. For now the goal of this article is to get people thinking of terminology and how to properly describe water flow. There are many ways to move water and many directions/speeds/volumes for it to go. To conclude, keep this in mind as we move forward in describing water flow.

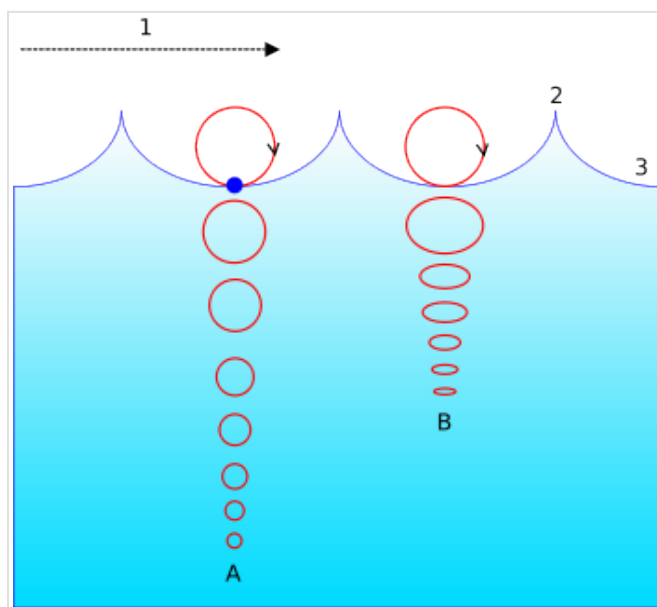


Photo Courtesy of Wikipedia

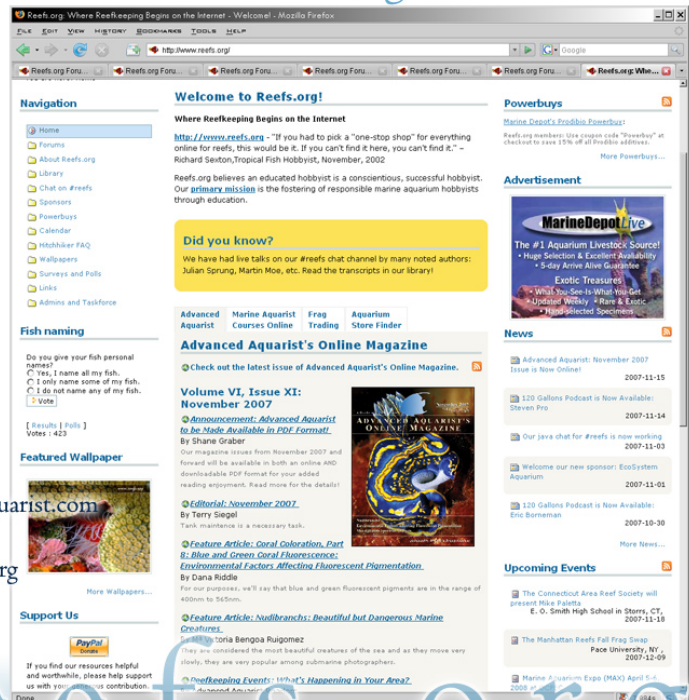


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AUTHOR INFORMATION

Adam Blundell M.S. works in Marine Ecology, and in Pathology for the University of Utah. He is also Director of The Aquatic & Terrestrial Research Team, a group which utilizes research projects to bring together hobbyists and scientists. His vision is to see this type of collaboration lead to further advancements in

aquarium husbandry. While not in the lab Adam provides services for one of the Nation's largest hobbyist clubs, the Wasatch Marine Aquarium Society (www.utahreefs.com). Adam has earned a BS in Marine Biology and an MS in the Natural Resource and Health fields. Adam can be contacted at adamblundell@hotmail.com.

HOT TIPS

HAVE YOU EVER ATTEMPTED TO BREED ANY OF YOUR LIVESTOCK? IF SO WHAT AND HOW?

By Advanced Aquarist's Readers

This month, our readers give tips on breeding livestock.

Published January 2008, Advanced Aquarist's Online Magazine.

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Keywords (AdvancedAquarist.com Search Enabled): Beginner, Breeding, Hot Tips, Novice

Link to original article: <http://www.advancedaquarist.com/2008/1/tips>

A selection of useful tidbits of information and tricks for the marine aquarist submitted by Advanced Aquarist's readership. Readers are encouraged to post them to our Hot Tips sticky in the Reefs.org [General Reefkeeping Discussion](#) forum or send their tips to terry@advancedaquarist.com for possible publication. This month's Hot Tip theme is "How do you choose a LFS?" Please head over to our discussion forum and post your thoughts!

HAVE YOU EVER ATTEMPTED TO BREED ANY OF YOUR LIVESTOCK? IF SO WHAT AND HOW?

I have raised Banggai cardinals. I just let them breed in my 225g tank but it had large 30in. deep overflows. They contained lots of rubble which was a breeding ground for mysid shrimp. Some of the young banggai made it the overflows and survived on pods, mysid shrimp and eventually frozen Cyclop-eeze, that was fed to the shrimp.

My current 4yr. old pair of Ora percs, lay eggs on a regular basis but I have not tried to raise any. We tried once with eggs from a pair of Cinnamon clowns. Their keeper removed the eggs and kept them in a small aquarium running on airstones & a heater. They did hatch and he was feeding the fry a store bought fry food. The young were doing fine when an accident unplugged the small aquarium.

My lawnmower blennie has layed eggs at least two times now. Usually high in the tank on the rear glass or rock. She then fans them, while trying to fend off others. The lack of a male to fertilize or the threat of the other fish, usually end the eggs existence. I would guess that even if a male was present, and the eggs hatched, they would end up the same as the young perc fry.

Submitted by D.W.L.

Yes. I have been working on breeding the dwarf cuttlefish *Sepia bandensis* for about 4 years. I have closed the life cycle several times, but have been unable to produce hatchlings in any great quantity. Still trying. I have about 200 gallons devoted to the project, and the hardest part has been a stable source on inexpensive live saltwater feeder animals. I am thinking of branching out to other cephalopods as well.

Soon I will also be getting several captive bred Banggai cardinals from different sources so I can breed them. They will probably go in my 180 gallon sump.

Captive breeding and captive propagation are important and I think more people should do it.

Submitted by Thales

ONLINE NEWS

REEFS IN THE NEWS

From Online News Sources

Media coverage of the state of our world's reefs, interesting information, and other marine-related news.

Published January 2008, Advanced Aquarist's Online Magazine.

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Link to original article: <http://www.advancedaquarist.com/marineneews>

NOAA HERITAGE WEEK: FEB. 2-10

NOAA Government News Releases
January 31, 2008 05:30 PM

As part of the Preserve America Initiative, NOAA is presenting an exhibit on Shipwrecks at it's Maryland-based headquarters.

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Source:
<http://preserveamerica.noaa.gov/heritageweek.html>

NOAA CAUTIONS PUBLIC TO AVOID SEAL PUPS ON CALIFORNIA BEACHES

NOAA News Releases
January 31, 2008 05:22 PM

NOAA's Gulf of the Farallones National Marine Sanctuary advises beachgoers against interacting with any seal pups they may find on the beach. Newborn harbor seal pups, born in late winter and spring, could suffer permanent harm if someone not licensed in marine mammal rescue were to move them.

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Source:
http://www.noaanews.noaa.gov/stories2008/20080131_sealpups.html

LAST STOP: THE GREAT BURIAL REEF (TIME MAGAZINE)

Yahoo! Coral Reefs News
January 31, 2008 04:43 PM

Jason Rew, president and CEO of Great Burial Reef, holds a solid maple urn containing cremated remains, which he will place in a manmade reef underwater.

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Source:
http://us.rd.yahoo.com/dailynews/rss/search/coral+reef/SIG=122dtr17h/*http%3A/www.time.com/time/health/article/0,8599,1708004,00.html

MARINE SANCTUARY LOOKS TO PROTECT BLUE WHALES (SANTA BARBARA INDEPENDENT)

National Marine Sanctuary in the News
January 31, 2008 02:08 PM

The feds debate how to protect whales in the Santa Barbara Channel.

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http://us.rd.yahoo.com/dailynews/rss/search/%22National+Marine+Sanctuary%22/SIG=12rrl554t/*http%3A/www.independent.com/news/2008/jan/31/marine-sanctuary-looks-protect-blue-whales/

DOLPHIN CONSERVATION COMMENDED

NOAA Government News Releases
January 31, 2008 02:03 PM

NOAA praises governments that signed the 1998 Agreement on the International Dolphin Conservation Program; dolphin deaths in Eastern Pacific Ocean have decreased dramatically.

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Source:
http://www.noaanews.noaa.gov/stories2008/20080130_dolphin.html

SCIENTISTS TO CHECK FOR DAMAGE TO CORALS ON GREAT BARRIER REEF (THE AUSTRALIAN)

Yahoo! Coral Reefs News
January 31, 2008 01:00 PM

SCIENTIFIC tests will be carried out on the Great Barrier Reef next week to see if recent floods in central and north Queensland have damaged it.

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http://us.rd.yahoo.com/dailynews/rss/search/coral+reef/SIG=12k7fnthl/*http%3A/theaustralian.news.com.au/story/0,,23141607-30417,00.html?from=public_rss

BEACH RESTORATION GETS SANDY BOOST (THE MAUI NEWS)

National Marine Sanctuary in the News
January 31, 2008 11:40 AM

WAILUKU â€" Work started Wednesday at Kamaole II Beach Park to repair the beach and sand dunes lost during Decemberâ€™s Kona storm.

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http://us.rd.yahoo.com/dailynews/rss/search/%22National+Marine+Sanctuary%22/SIG=11f2355us/*http%3A/www.mauinews.com/story.aspx?id=38298

WATER QUALITY POSES THREAT TO CORAL REEFS (KHNL NEWS 8 HONOLULU)

Yahoo! Coral Reefs News
January 31, 2008 10:47 AM

In conjunction with the "International Year of the Reef", Monday night we explore the undersea world of coral reefs, and the issues that surround their survival.

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Source:

http://us.rd.yahoo.com/dailynews/rss/search/coral+reef/SIG=11i85o3pq/*http%3A/www.khnl.com/Global/story.asp?S=7800926

DAILY EXPRESS NEWS (SABAH DAILY EXPRESS)

Yahoo! Coral Reefs News
January 31, 2008 06:28 AM

Kota Kinabalu : The recovery process of the damaged coral reef at Pulau Sipadan following the 2006 barge incident is now almost complete, according to Sabah Parks.

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Source:

http://us.rd.yahoo.com/dailynews/rss/search/coral+reef/SIG=11o579tk7/*http%3A/www.dailyexpress.com.my/news.cfm?NewsID=55629

BAY PROJECT REEF TO BE DESTROYED (GULF DAILY NEWS)

Yahoo! Coral Reefs News
January 30, 2008 11:06 PM

A CORAL reef standing in the way of development of the \$2.5 billion (BD945 million) Bahrain Bay is to be ripped out, following a U-turn by Manama Municipal Council yesterday. The decision comes just two days after experts warned at a conference in Bahrain that the region is sitting on an environmental time-bomb, thanks to massive and "reckless" land reclamation.

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http://us.rd.yahoo.com/dailynews/rss/search/coral+reef/SIG=12hqo6dvr/*http%3A/www.gulf-daily-news.com/Story.asp?Article=207333&Sn=BNEW&IssueID=30317

SUNSCREEN HARMFUL TO CORAL REEFS (THE TIMES OF INDIA)

Yahoo! Coral Reefs News
January 30, 2008 08:23 PM

WASHINGTON: The sunscreen which you apply before going for a swim on the beach might be killing coral reefs worldwide, a new research has shown.

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Source:

http://us.rd.yahoo.com/dailynews/rss/search/coral+reef/SIG=12vick5l8/*http%3A/timesofindia.indiatimes.com/Sunscreen_harmful_to_coral_reefs/articleshow/2744624.cms

VETERAN RESEARCH PILOT TO HEAD NOAAâ€™S AVIATION WEATHER CENTER

NOAA News Releases
January 30, 2008 05:05 PM

NOAA has named Robert Maxson director of the Aviation Weather Center in Kansas City, the nationâ€™s primary source of weather information for domestic and international flights. Maxson will leave his post as a research pilot with the National Science Foundation in Boulder, Colo. and begin his new duties at NOAA on Feb. 4.

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Source:

http://www.noaaanews.noaa.gov/stories2008/20080130_maxson.html

BIG ISLAND HAS MOST LIVE CORAL OF MAIN HAWAIIAN ISLANDS

ScienceDaily: Coral Reef News
January 30, 2008 01:00 PM

New coral reef maps released by NOAA reveal that the Big Island of Hawaii has the highest percentage of live coral of the main Hawaiian islands. The finding supports studies indicating that geologically young islands such as the Big Island generally have more live coral cover than older islands. "Live coral covers 57 percent, or 29 square miles, of the waters surrounding the Big Island of Hawaii," said an oceanographer with NOAA's Center for Coastal Monitoring and Assessment. "That is the most live coral coverage of any of the main Hawaiian islands."

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Source:
<http://www.sciencedaily.com/releases/2008/01/080124120725.htm>

CLEANUP OF TAR BALLS RESUMES AT BEACHES (THE DAILY REVIEW)

National Marine Sanctuary in the News
January 30, 2008 11:05 AM

Cleanup crews spent their second day removing a fresh batch of tar balls from the beaches of San Mateo County as the mystery oil likely claimed its first two bird victims – two rhinoceros auklets found dead on a county beach.

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Source:
http://us.rd.yahoo.com/dailynews/rss/search/%22National+Marine+Sanctuary%22/SIG=11mo7m8bi/*http%3A/www.insidebayarea.com/ci_8117406?source=rss

ECOLOGISTS WORRY FLOODWATERS WILL HURT REEF (ABC VIA YAHOO!7 NEWS)

Yahoo! Coral Reefs News
January 29, 2008 11:00 PM

Environmental researchers predict freshwater flowing down the Fitzroy River to the Great Barrier Reef will kill off masses of coral around the Keppel Islands in central Queensland.

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Source:
http://us.rd.yahoo.com/dailynews/rss/search/coral+reef/SIG=11h06hl7g/*http%3A/au.news.yahoo.com/080129/21/150eb.html

OVERPOPULATION KILLING CARIBBEAN CORAL REEFS (CYBER DIVER NEWS NETWORK)

Yahoo! Coral Reefs News
January 29, 2008 07:18 AM

CARIBBEAN (9 Jan 2008) – Coral reefs in the Caribbean have suffered significant changes due to the proximal effects of a growing human population, reports a new study.

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Source:
http://us.rd.yahoo.com/dailynews/rss/search/coral+reef/SIG=11jqolzd9/*http%3A/www.cdn.info/news/science/sco80109.html

QLD FLOODWATERS THREATEN GBR (ABC VIA YAHOO!7 NEWS)

Yahoo! Coral Reefs News
January 29, 2008 01:38 AM

The Great Barrier Reef Marine Park Authority says freshwater flowing out onto the reef from the flooded Fitzroy River may cause some damage to coral.

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Source:
http://us.rd.yahoo.com/dailynews/rss/search/coral+reef/SIG=11hgdgarp/*http%3A/au.news.yahoo.com/080129/21/1501y.html

CARIBBEAN CORAL REEFS UNDER INCREASING THREAT - UN (SCOOP.CO.NZ)

Yahoo! Coral Reefs News
January 28, 2008 08:37 PM

28 January 2008 - Warming temperatures and increasing storms are posing serious threats to Caribbean coral reefs and the people who depend on them for their livelihoods, the United Nations Educational, Scientific and Cultural Organization (UNESCO) said today.

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Source:
http://us.rd.yahoo.com/dailynews/rss/search/coral+reef/SIG=11kmcusgt/*http%3A/www.scoop.co.nz/stories/WO0801/Soo278.htm

VOLUNTEERS COUNT WHALES IN NOAA'S HAWAIIAN ISLANDS HUMPBACK WHALE NATIONAL MARINE SANCTUARY

NOAA News Releases
January 28, 2008 06:55 PM

More than 600 volunteers gathered data from the shores of Oahu, Kauai, the Big Island, and Kahoolawe for Saturday's annual Hawaiian Islands Humpback Whale National Marine Sanctuary Ocean Count on Jan. 26.

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Source:
http://www.noaanews.noaa.gov/stories2008/20080128_sanctuary.html

SHIP TO BECOME ARTIFICIAL REEF IN KEY WEST (NBC 6 MIAMI)

National Marine Sanctuary in the News
January 28, 2008 06:38 PM

Officials overseeing the transformation of a retired U.S. Air Force missile tracking ship into an artificial reef off Key West say they plan to sink the ship May 15.

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Source:
http://us.rd.yahoo.com/dailynews/rss/search/%22National+Marine+Sanctuary%22/SIG=122lsr2hh/*http%3A/www.nbc6.net/news/15152280/detail.html?rss=ami&psp=news

ADMIRAL SAYS OIL SPILL ALERT WAS TOO SLOW (VALLEJO TIMES-HERALD)

National Marine Sanctuary in the News
January 28, 2008 06:21 PM

A new report on the response to a November ship collision and fuel leak in San Francisco Bay found shortcomings in the Coast Guard's public communications but concludes that crews responded rapidly to the spill, the agency's top officer in California says.

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Source:
http://us.rd.yahoo.com/dailynews/rss/search/%22National+Marine+Sanctuary%22/SIG=11fkbkfq/*http%3A/www.timesheraldonline.com/ci_8099400

WORLD'S CORAL REEFS FACE RENEWED THREATS (NPR)

Yahoo! Coral Reefs News
January 27, 2008 05:16 PM

Researchers gathered in Washington this week to launch "The Year of the Coral Reef." That work has taken on renewed importance in the wake of two new studies showing that reefs are facing more threats than ever.

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Source:
http://us.rd.yahoo.com/dailynews/rss/search/coral+reef/SIG=12d3kb01e/*http%3A/www.npr.org/templates/story/story.php?storyId=18456171&ft=1&f=1007

DEWITT JUNIOR HIGH SCHOOL RECEIVES REEF AQUARIUM (DEWITT-BATH REVIEW)

Yahoo! Coral Reefs News
January 27, 2008 03:34 PM

DEWITT "The DeWitt Middle School's media center recently received a 50-gallon reef aquarium from the Mid-Michigan Marine Club (MMMC). The classroom reef provides a hands-on and fun learning experience for students.

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Source:
http://us.rd.yahoo.com/dailynews/rss/search/coral+reef/SIG=12ha2731v/*http%3A/www.lsj.com/apps/pbcs.dll/article?AID=/20080127/DEWITTBATH02/801270662

WHALE COUNTS SUCCESSFUL DESPITE WEATHER (THE GARDEN ISLAND)

National Marine Sanctuary in the News
January 27, 2008 03:29 PM

Angela Tillson, the site leader for the Ahukini Ocean Count, was trying to make light of the blustery weather that greeted her group of nine whale counters yesterday morning.

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Source:
http://us.rd.yahoo.com/dailynews/rss/search/%22National+Marine+Sanctuary%22/SIG=11t337htd/*http%3A/kauaiworld.com/articles/2008/01/27/news/news05.txt

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Premium Aquatics is a family owned and operated aquarium business. We have been in business since April 1996 and we are dedicated to serving the aquarium hobbyist. Our mission is to bring you the highest quality aquarium products and livestock available and at a reasonable price and to provide honest non-bias information on all of our products and our competitors. Our goal is customer satisfaction, we want your return business.

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AquariumPart.com is an online retailer of many hard to find parts for various aquarium lights, pumps, protein skimmers, meters, UV sterilizers and filters.

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